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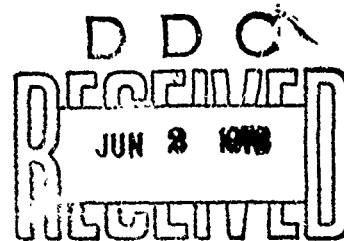
# Final Report of OT-45, PVM-8, and RVTO Weather Documentation AFCRL/Minuteman Report No. 5

JAMES I. METCALF, Capt, USAF  
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23 July 1975

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One of the OT-45 RV's passed through clouds below 6 km, but the values of Weather Severity Index (WSI) were less than 0.1 for all the trajectories. The PVM-8 RV's passed through clouds at 14 km, 8 to 12 km, and below 6 km with maximum water content of 0.0015, 0.005, and 0.03 gm/m<sup>-3</sup> respectively. WSI was 0.1 for RV1 and 0.2 for RV2. The RVTO reentry weather was clear except for thin scattered cirrus above 10 km altitude (water content less than 0.001 gm/m<sup>-3</sup>). Simultaneous weather measurements were performed by aircraft and radar in the link-offset mode, in which the radar weather data were recorded at a fixed distance ahead of the aircraft.

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## Preface

Field work at Kwajalein Missile Range under the Minuteman Natural Hazards Program was conducted from 17 July through 24 August and 9 September through 14 October 1974. During these periods weather data support was provided for three clear-air tests. These were the SAC OT-45 on 17 August, the Minuteman PFM-8 on 5 October, and the ABRES RVTO on 14 October. Because of the similarity of the weather criteria for these missions, the evaluations of the reentry weather are combined in this report.

The field support included representatives of SAMSO/MN; SAMTEC/WE; 6th Weather Wing; AFSWC; AFCRL Meteorology Laboratory; TRW Systems Group; Meteorology Research, Inc.; Science Applications, Inc.; Particle Measuring Systems, Inc.; and Alpine Air Charter. SAMSO/TRW was responsible for the overall planning and operation of the weather program.<sup>1</sup> The roles of the other organizations are described in our report. MRI was responsible for the operation of the instrumentation on the Citation aircraft (except the holographic camera), and readers interested in more details of the equipment or data than are presented here are referred to the MRI final reports for OT-45 and PVM-8.<sup>2,3</sup> The

1. Wilmot, R.A., Cisneros, C.E., and Guiberson, F.L. (1974) High cloud measurements applicable to ballistic missile systems testing, 6th Conf. Aerosp. and Aeronaut. Meteor., Amer. Meteor. Soc., pp 194-199.
2. Jahnsen, L.J., and Heymsfield, A.J. (1975) Final Report of OT-45 Mission - Weather Measurements and Analysis of Citation Cloud Particle Instrumentation, MRI 75 FR-1314, Meteorology Research, Inc., Altadena, Calif.
3. Jahnsen, L.J., and Heymsfield, A.J. (1975) Final Report of PVM-8 Mission - Weather Measurements and Analysis of Citation Cloud Particle Instrumentation, MRI 75 FR-1288, Meteorology Research, Inc., Altadena, Calif.

holographic camera is described in the SAI final report<sup>4</sup> and in a special MRI report.<sup>5</sup>

Reports prepared to date in the AFCRL/Minuteman Series are as follows:

1. Aircraft and radar weather data analysis for PVM-5 (AFCRL-TR-74-0627, 23 December 1974). *BOO4 290L*
2. Final report of PVM-4 and PVM-3 weather documentation (AFCRL-TR-75-0097, 14 February 1975). *BOO4 427L*
3. Final report of STM-8W weather documentation (AFCRL-TR-75-0207, 11 April 1975). *BOO6 666L*
4. Final report of PVM-5 weather documentation (AFCRL-TR-75-0302, 28 May 1975). *BOO6 667L*

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4. Trolinger, J.D., Farmer, W.M., and Clayton, F.P. (1974) Development and Application of an Airborne Holography System and Particle Sizing Interferometer, SAI-74-511-TT, Science Applications, Inc., La Jolla, Calif.
  5. Jahnsen, L.J. (1975) Utilization of SAMSO Airborne Holocamera for Cloud Physics Measurements, MRI 75 FR-1331, Meteorology Research, Inc., Altadena, Calif.

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## **Final Report of OT-45, PVM-8, and RVTO Weather Documentation AFCRL/Minuteman Report No. 5**

### **1. INTRODUCTION**

The OT-45 mission was launched on 17 August 1974, with reentry near Kwajalein Atoll at 1651Z. The Minuteman PVM-8 mission was launched on 5 October 1974, with reentry at 0641Z, and the RVTO mission was launched on 14 October 1974 with reentry at 0417Z. The "minimum weather" criterion for each of these missions was satisfied. This report describes the weather data acquisition plan and presents our final determination of the water content profiles encountered by the reentry vehicles. Data from various meteorological sensors are presented to provide further details on the weather in the vicinity of the target areas.

Descriptions of each of the sensors are included in this report with the presentations of data in the following sections. The locations of the various supporting facilities are shown in Figure 1. The NWS rawinsonde and weather radar facilities, and the DMSP satellite van operated by the 6th Weather Wing from McClellan AFB were located on Kwajalein Island. The Lincoln Laboratory radars, located at KREMS on Roi-Namur Island, were used to obtain weather data on the reentry trajectories. NWS rawinsonde facilities at Roi-Namur were used for soundings in conjunction with the missions, in addition to the soundings from Kwajalein. A Cessna Citation aircraft, operated by Alpine Air Charter on contract to MRI, and a C-130E aircraft, operated by AFSWC from Kirtland AFB and instrumented for cloud physics measurements by AFCRL, were based at Kwajalein during the July (Received for publication 22 July 1975)

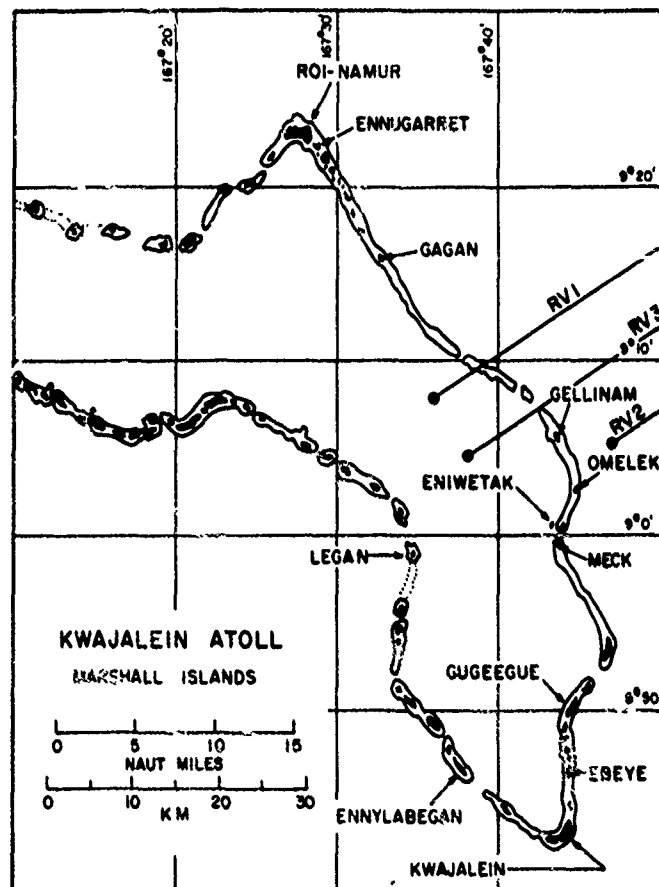


Figure 1. Kwajalein Atoll, Showing the Islands Occupied by the Facilities of Kwajalein Missile Range. Range Operations Control Center, aircraft support facilities, NWS radars, and MPS-36 radars are at Kwajalein Island. Lincoln Laboratory radars are at Roi-Namur Island. Trajectories of the OT-45 RV's are shown. PVM-8 followed the same trajectory as OT-45 RVI, with RV2 about 2 km to the north. RVTO target was about 35 km northeast of the OT-45 RV2 target

to October field program. Both aircraft performed weather sampling in support of PVM-8, and the Citation alone for OT-45 with the C-130E as a backup. The C-130E provided exclusive airborne weather support for RVTO.

Execution of the weather data acquisition plan and on-site evaluation of the data were the responsibilities of the mission Weather Team. The Weather Team included representatives of AFCRL, SAMSO, SAMTEC, TRW, and MRI at the

ROCC and an AFCRL radar meteorologist at KREMS. An AFCRL Meteorological Flight Director and two AFCRL instrumentation technicians flew on the C-130E.

The reentry weather was defined in terms of the Weather Severity Index

$$WSI = \int_{h_1}^{h_2} M h dh, \quad (1)$$

where  $M$  is the water content ( $\text{gm m}^{-3}$ ),  $h_1$  is the height (km) of the lowest cloud base, and  $h_2$  is the height of the highest cloud top on the trajectory. For a series of thin layers, or for numerical integration across a thick cloud layer this may be approximated by

$$WSI \approx \sum_i M_i \bar{h}_i \Delta h_i, \quad (2)$$

$$\begin{aligned} &\approx \sum_i M_i \frac{(h_i + h_{i-1})}{2} (h_i - h_{i-1}), \\ &= \sum_i M_i \frac{h_i^2 - h_{i-1}^2}{2}. \end{aligned} \quad (3)$$

The nominal criterion for "minimum weather" is  $WSI < 1$ , although there were additional weather criteria for OT-45 associated with SAC scoring requirements. These required that there be no showers in the immediate vicinity of the impact points that would interfere with the splash-detection radars.

The OT-45 RV's encountered a few thin cloud layers. There were three weak echo layers below 4 km on the RV1 trajectory. Clouds were detected on the RV2 trajectory below 6 km, with maximum liquid water content about  $0.008 \text{ gm m}^{-3}$  at 5.8 km. No clouds were detected on the RV3 trajectory. Hence, the WSI was much less than one on each of the trajectories. The Citation sampled some convective cells that were in the vicinity, and made two passes for correlation with ALCOR, but encountered very few ice crystals or droplets outside of the convective cells.

The PVM-8 RV's passed through thin clouds near 14 km, and 8 to 12 km, and through showers below 6 km. Maximum water content encountered by the RV's was approximately  $0.0015 \text{ gm m}^{-3}$  at 14 km and  $0.005 \text{ gm m}^{-3}$  near 10 km in ice clouds, and  $0.03 \text{ gm m}^{-3}$  in rain at 3 km (RV2). The WSI's were 0.1 and 0.2 for RV1 and RV2 respectively. The C-130E and the Citation observed and sampled water clouds between 3 and 6 km and cirrus clouds between 9 and 12 km. Eight data passes were made for correlation with ALCOR, and provided good data for interpreting the radar data on the trajectories.

The RVTO weather was clear, with no radar-detectable clouds on the trajectory. The C-130E confirmed the absence of clouds with the exception of very thin scattered cirrus above 10 km.

## 2. OT-45 WEATHER DESCRIPTION

The reentry weather was essentially clear, although there were some convective cells in the area. The DMSP satellite picture at 1304Z (Figure 2), nearly four hours before the reentry, showed the immediate vicinity of Kwajalein to be nearly cloud-free. However, there were scattered high-level clouds in the area, and some convective cells as little as 75 km to the south and 110 km to the southeast.

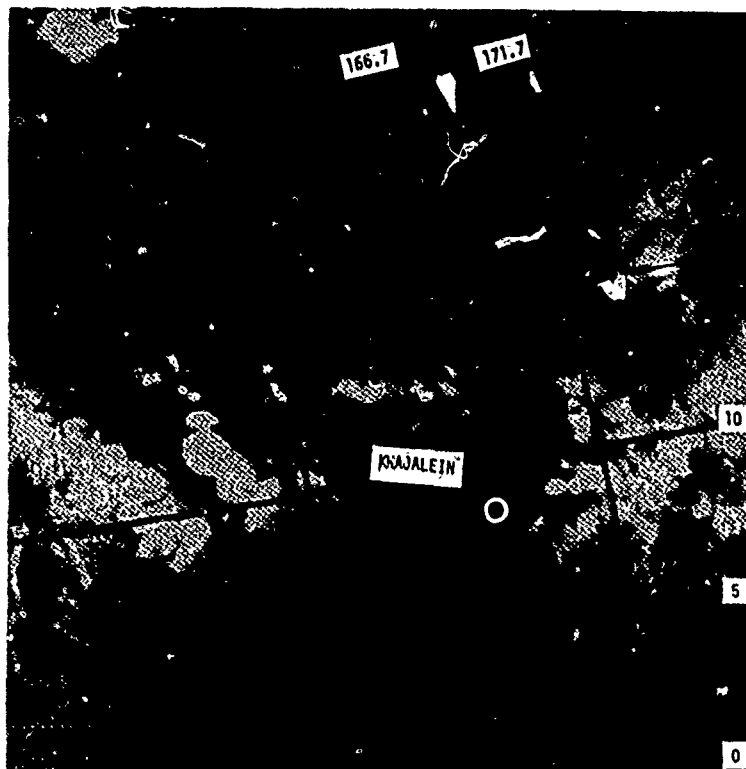


Figure 2. DMSI Satellite Infrared Data for 17 August 1974, 1304Z. Immediate vicinity of Kwajalein is nearly cloud-free, but some small cells are visible 75 to 100 km south and southeast. Most significant convective activity is about 200 km to the east

An extensive area of convective activity was within 200 km of Kwajalein to the east, but there were no significant convective clouds within 400 km to the north or west. Closer to the time of reentry there was more convective activity in the target area, which necessitated a launch hold for optical tracking. By the time of reentry, most of this activity was confined to the area to the north of the reentry corridor. Because the winds were from the north through a considerable depth of the atmosphere there was a possibility of advection of ice crystals from these clouds into the corridor. The MRI analysis<sup>2</sup> showed some evidence of this effect, but the values of ice water content they computed away from the convective clouds did not exceed  $0.0072 \text{ gm m}^{-3}$ , the maximum they observed near 8 km altitude shortly after the reentry.

Convective cells observed close to the time of reentry were moving toward the east-northeast with the winds below 2 km. The 10-cm WSR-57 radar, which detects precipitation but not non-precipitating clouds, showed that one of these cells had moved just beyond the reentry corridor at the time of the reentry (Figure 3). This cell had been observed first over the lagoon, reached a maximum height of about

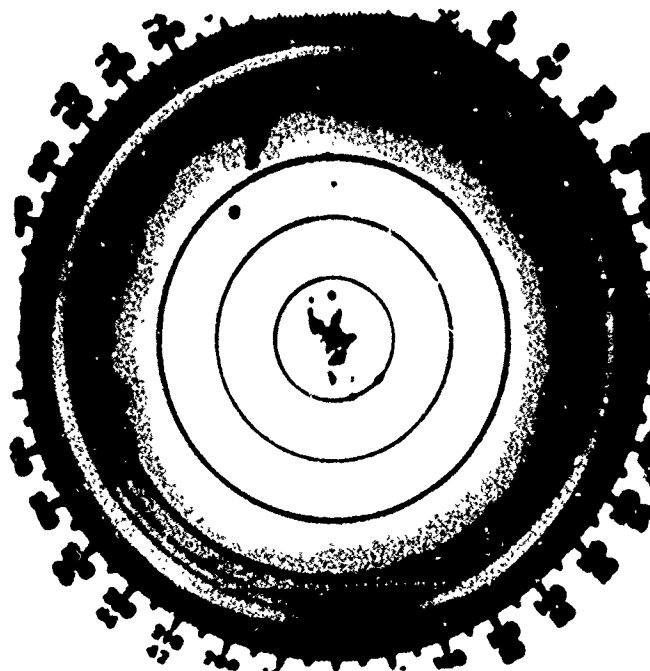


Figure 3. WSR-57 Radar PPI at 1645Z, 17 August 1974. Elevation angle is  $0^\circ$  and range markers are at 25 n. mi. (46.3 km) intervals out to 125 n. mi. (231.5 km). Heavy showers are seen to the west and northwest over Roi-Namur Island. Cell at 90 km range and  $30^\circ$  azimuth has moved through the reentry area and uprange of the trajectories just prior to the reentry

10 km, and was dissipating by the time of reentry. The Citation sampled this cell at 9.3 km altitude about one hour before reentry, and reported ice water content of  $0.3 \text{ gm m}^{-3}$ . A sequence of RHI scans with the WSR-57 between 1645 and 1700Z at azimuths between  $28^\circ$  and  $345^\circ$  (moving counterclockwise) showed that the echo top was at 7 km altitude and 70 km range on the  $28^\circ$  azimuth. No other weather echoes were detected in the reentry corridor.

The NWS sounding from Kwajalein at 1655Z is shown in Figure 4. The post-impact sounding from Roi-Namur could not be made due to icing on the balloon. This was the result of the heavy showers at Roi-Namur at that time, which can be seen in Figure 3. A second rawinsonde (Figure 5) was released from Roi-Namur at 1847Z, shortly after the time that the Citation completed its post-mission cloud sampling operations. Both soundings measured high humidity ( $\text{RH} > 75$  percent with some regions of 95 to 100 percent) from the surface to 5.2 km, with relatively

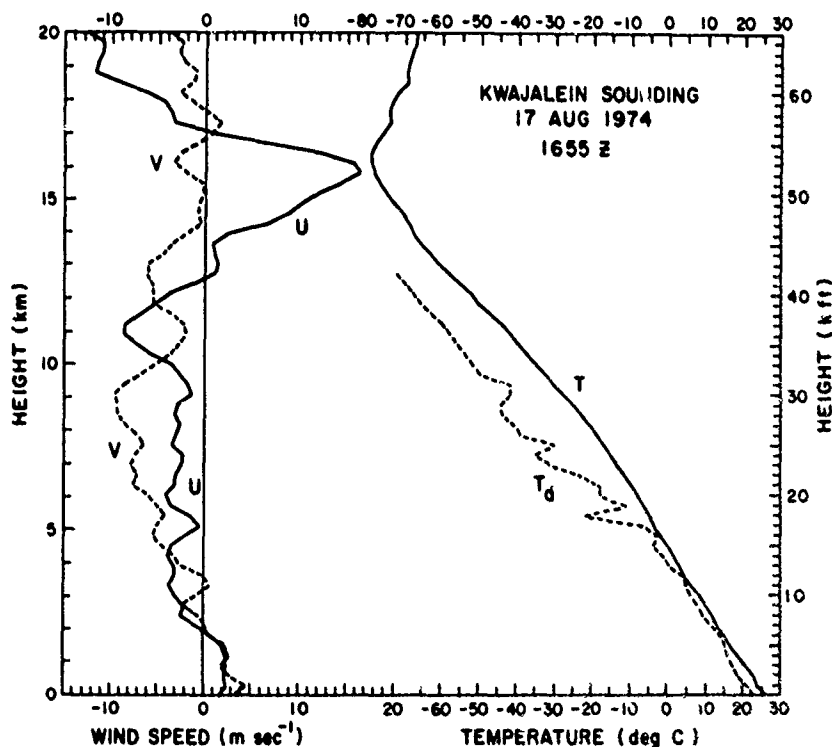


Figure 4. Sounding From Kwajalein at 1655Z, 17 August 1974. Wind components are plotted toward the east (U) and toward the north (V). Humidity is high from the surface to about 5 km and quite low at higher altitude. Winds are southwesterly in the lowest 2 km, northeasterly between 4 and 12 km, and sharply from the northwest just below the tropopause

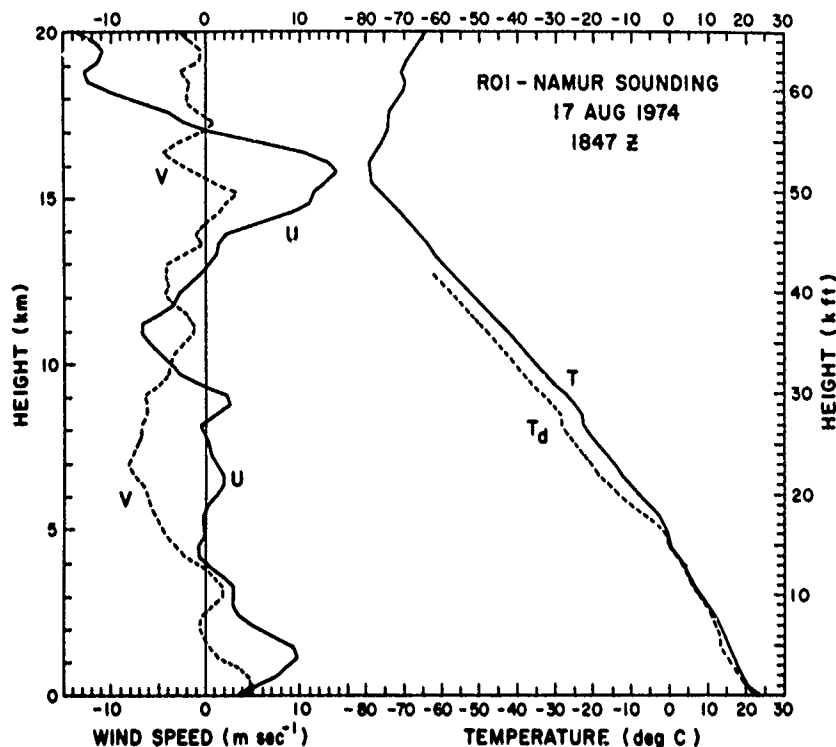


Figure 5. Sounding From Roi-Namur at 1847Z, 17 August 1974. Format is identical to that of Figure 4. Atmosphere is more humid than over Kwajalein Island at all levels, due to vigorous convection and thick clouds near Roi-Namur. Low-level wind is more westerly than in the earlier sounding, extending to about 3.7 km with speeds up to  $9.8 \text{ m sec}^{-1}$  at 1.2 km. Wind between 4.3 and 9.5 km is northerly, with speeds up to  $8.2 \text{ m sec}^{-1}$ . Wind structure at higher levels is similar to that shown in Figure 4.

dry air above. Southwesterly winds extended from the surface to 1.8 km at 1655Z and to 3.7 km at 1847Z with a maximum speed of  $5 \text{ m sec}^{-1}$  in the early sounding and  $10 \text{ m sec}^{-1}$  in the later one. Above the southwesterly flow the Kwajalein sounding showed winds generally from the northeast quadrant with speeds up to  $10 \text{ m sec}^{-1}$  at 8.5 to 9 km. Just below the tropopause, which was at 16 km, the wind backed sharply to the northwest and west and attained a speed of  $16 \text{ m sec}^{-1}$ . Above the tropopause, and to the top of the sounding at 33.5 km, the winds were easterly. The later sounding from Roi-Namur showed similar features, except that the winds between 4 and 9.5 km were north-northwesterly, rather than north-northeasterly as in the earlier sounding.

The vertically-pointing 0.86-cm TPQ-11 radar at Kwajalein, which can detect non-precipitating clouds, showed no clouds overhead at the time of the reentry. An intermittent layer at 1.8 km was detected up to about 1600Z and after 1730Z, and

a thin layer at 3.7 km had disappeared by 1630Z. The NWS surface observation from Kwajalein at the time of impact was 1/10 coverage of scattered cumulus at 430 m (1400 ft), less than 1/10 scattered altocumulus at 3.7 km (12 kft), and about 5/10 thin scattered cirrostratus at 10.7 km (35 kft). The reentry was observed clearly from Kwajalein, but could not be seen from Roi-Namur due to the local showers.

### 3. CITATION WEATHER OBSERVATIONS FOR OT-45

A Cessna Citation aircraft instrumented by MRI provided in situ measurements of cloud parameters for this mission. The Citation operations on 17 August 1974 are summarized in Table 1. The primary objectives were to obtain profiles of ice water content in the reentry corridor close to the time of reentry and to obtain data in conjunction with ALCOR for the derivation of Z-M equations.

Table 1. Citation Operations at Kwajalein, 17 August 1974

Time GMT	Pressure Altitude		Remarks
	(kft)	(km)	
1217 to 1229	20 -32	6.1-9.8	Ascent on 058° hdg from Target 1
1244 to 1248	30	10.0*	
1255 to 1258	27.5	9.2	
1516 to 1531	20 -32	6.1-9.8	Ascent on 058° hdg from Target 1
1538 to 1540	28	9.3*	Near top of convective cell
1546 to 1550	29	10.1*	
1625 to 1629	35 -20	11.7-6.1*	Descent on 238° hdg toward Target 1
1714 to 1719	37.3-20	12.4-6.1*	Descent on 238° hdg toward Target 1
1745 to 1749	25	8.0**	Correlation sampling with MPS-36 and ALCOR
1806 to 1810	18	5.7**	Correlation sampling with MPS-36 and ALCOR

\*Altitude from MRI data listing.

\*\*Altitude from ALCOR tracking data.

The cloud physics instrumentation has been described in detail by Jahnsen and Heymsfield.<sup>2</sup> The probes were mounted in the nose baggage bay, in the emergency exit door, and in a fixed window. A technician flew in the Citation to monitor instrument performance and to report meteorological observations to the Weather Team.

The principal instruments were the PMS probes, which measured particle sizes in the ranges 1 to 31  $\mu\text{m}$  (axially scattering spectrometer), 28 to 310  $\mu\text{m}$  (optical array cloud particle spectrometer), and 234 to 3100  $\mu\text{m}$  (optical array precipitation particle spectrometer).<sup>\*</sup> Each spectrometer recorded particle counts in fifteen size channels. A Formvar particle replicator (MRI Model 1203B) provided a continuous record of the types of hydrometeors encountered by the aircraft. Images of particles greater than 2  $\mu\text{m}$  in length were preserved in an adhesive resin applied to a 16-mm sampling tape. These data are essential to the analysis of the PMS data, as the computation of ice water content and reflectivity from the one-dimensional size spectra requires an approximation of the crystal habit. A second hydrometeor sampler (MRI Model 1220 foil impactor) recorded images of particles greater than 250  $\mu\text{m}$  in size on a thin metallic film. Additional instrumentation measured temperature, pressure altitude, and indicated airspeed, which were recorded along with observations by the crew.

A holographic camera developed and operated by RAI<sup>4</sup> was also installed on the Citation. This system utilized a pulsed ruby laser to produce holograms of a cylindrical sample volume 5 cm in diam and 15 cm long at a rate of 3 per min. A three-dimensional image of the sample volume can be reconstructed from each hologram, and individual crystals can be observed with a resolution of about 50  $\mu\text{m}$ . The holographic camera was operated throughout the July to October 1974 period, but due to technical problems was not operated on the OT-45 mission day.

The first Citation flight, from 1205 to 1410Z, included an ascent in the reentry corridor and two level runs. Computer ice water content from the ascent was less than  $0.003 \text{ gm m}^{-3}$ , and the reentry area appeared generally clear. Convective activity was noted to the north of the corridor, over Roi-Namur, as described in Section 2. The second flight, from 1503 to 1830Z, included one ascent and two descents in the reentry corridor and several level runs, two of which were for correlation data with ALCOR. More convective cells were noted in the reentry area during the early part of this flight, including one large cell which moved through the corridor during the final stages of the countdown. The Citation sampled this cloud at 9.3 km, obtaining ice water content values of up to  $0.3 \text{ gm m}^{-3}$ , and observing predominantly plate crystals with some aggregation. There appeared to be relatively little blow-off of ice crystals from the convective cells in the corridor, although the later profiles of ice water content indicated an increase due probably to advection of ice crystals from the convective region over Roi-Namur.

After the reentry two correlation passes were flown in conjunction with ALCOR weather measurements. These followed the ground track of RV1 shown in Figure 1, and were conducted in the link-offset mode. In this mode the aircraft track file from the MPS-36 tracking radar was fed into the PRESS computer, offset by a constant vector (3 km) in the direction of flight, and used to control ALCOR. Thus the

<sup>\*</sup>These are outside limits of the size ranges, rather than the range of center diameters of the channels.

radar weather measurements were made at a constant distance ahead of the aircraft. MRI computed values of ice water content and reflectivity factor by approximating the ice crystal habit with 100 percent dendrites. Ice water content was less than  $0.01 \text{ gm m}^{-3}$  at both altitudes. Correlations of Z and M derived from the aircraft data alone are shown in Figure 6. The computed Z values were within a few dB of the ALCOR reflectivity values, but the latter were so close to the radar system noise level that no correlation between the aircraft and radar data was possible.

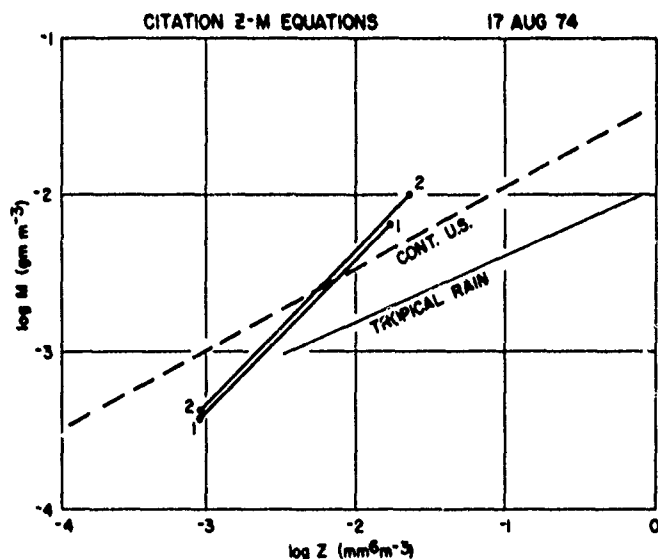


Figure 6. Z-M Equations Used to Interpret OT-45 Radar Weather Data. Lines designated "1" and "2" are derived exclusively from PMS data, as weather reflectivity values measured by radar during the correlation passes were too close to the system noise level. These are plotted only within the range of Z and M values used in their derivation. Eqs. (7) and (8), designated "Cont. U.S." and "Tropical Rain," are shown for comparison. Eq. (8) was used to interpret the low-level echoes from water clouds

The Z-M equations from the aircraft data were used to interpret the upper part of the trajectory reflectivity scans presented in the following section. The computed values of ice water content are accurate to about  $\pm 3$  dB in the range of Z values for which the correlations were derived. Extrapolation of the correlation line beyond this range is probably not valid.

Numbers of crystals encountered by the aircraft were generally quite small, except during the pass through the top of the convective cell and during the 10.1-km

pass at 1546Z, when ice water content as high as  $0.6 \text{ gm m}^{-3}$  was observed. Ice crystals observed during the correlation passes were predominantly dendrites, although some very small particles appeared to be frozen spheres.

#### 4. ALCOR WEATHER OBSERVATIONS FOR OT-45

Weather data were recorded by ALCOR throughout the July to October 1974 period while the Weather Team was at KMR. Operations in support of the OT-45 weather documentation are summarized in Table 2. The weather data evaluation involved the PRESS B-6 tape radar cross-section data and the SPA-40 RHI display which have been described in earlier reports in the AFCRL/Minuteman series. The details of the B-6 data processing are presented in Appendix A.

Table 2. ALCOR/PRESS Weather Support for OT-45, 17 August 1974

RHI scans at 0820, 0822, 0823Z		
Trajectory weather scans		Max WSI*
0804 to 0808		0.2 (RV2)
0928 to 0932		0.1 (RV1)
1315 to 1319		0.2 (RV3)
1452 to 1455		1.9 (RV3, shower ceil at 0-8 km); others <0.1
Post-impact scans		Weather structure
1651:17 to 1652:04	RV1	Thin layers below 4 km
1652:33 to 1653:20	RV2	3 to 6 km
1653:43 to 1654:36	RV3	No clouds
1655:00 to 1655:13	Vertical	
1655:38 to 1656:26	RV1	Thin layers below 4 km
1656:55 to 1657:42	RV2	3 to 6 km
1658:11 to 1658:58	RV3	No clouds
1659:22 to 1659:35	Vertical	
RHI scans at 1755, 1758, 1759Z		
Aircraft correlations	Alt (km)	Hdg (deg)
1744:47 to 1748:29	8.0	058
1805:33 to 1809:21	5.7	238

\*WSI computed from Eqs. (3) and (7)

In addition to the data recorded on the B-6 tape, data were recorded at ALCOR in the same manner as for previous missions. The ALCOR data tapes were processed by Lincoln Laboratory and provided to AFCRL with calibrated radar signal values at 170 range gates spaced across a 2.5-km data window. These yielded a two-dimensional view of the weather structure along the trajectories. Final processing and analysis of these data were done by ERT programmers and AFCRL scientists, respectively. The flow of radar weather data, and related data and communications, is shown in Figure 7.

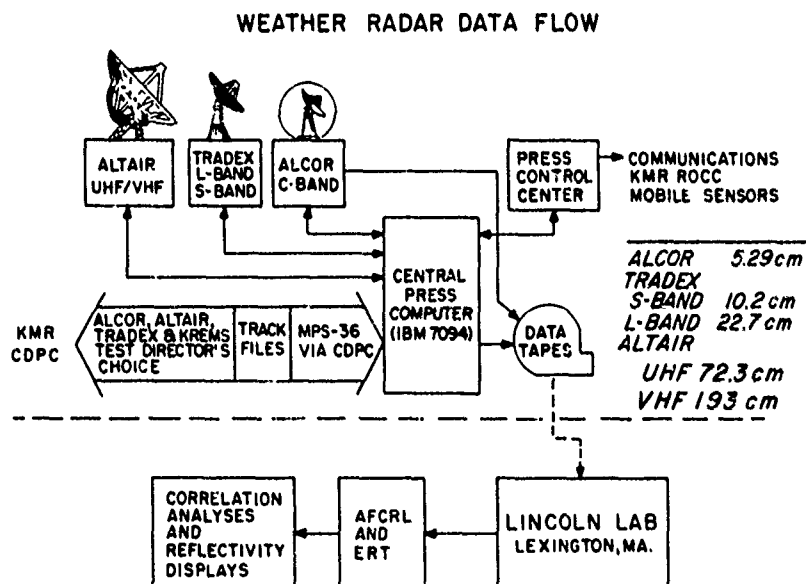


Figure 7. Radar Weather Data Flow Diagram. ALCOR is the principal weather sensor, with TRADEX S-band as backup. TRADEX L-band and ALTAIR were not used for weather measurements. ALCOR data are recorded on the PRESS B-6 for on-site processing of 1-sec averages, and also recorded directly for later processing at Lincoln Laboratory. Final processing and analysis are done by ERT programmers and AFCRL scientists

The reflectivity factor  $Z$  ( $\text{mm}^6 \text{m}^{-3}$ ) was computed by the equation

$$Z = C\sigma/r^2, \quad (4)$$

or

$$\text{dBZ} = 10 \log C + 10 \log \sigma - 20 \log r, \quad (5)$$

where  $\sigma$  is the cross-section ( $\text{m}^2$ ),  $r$  is the range (km), and

$$C = \left[ \frac{\lambda^4 \times 10^{10}}{\pi^5 \times |K|^2} \right] \left[ \frac{8 \ln 2}{\pi \theta^2 h \times 10^6} \right]. \quad (6)$$

where  $\lambda$  is the wavelength (5.30 cm),  $h$  is the pulse length (37.5 m),  $\theta$  the beam-width ( $5.24 \times 10^{-3}$  rad), and  $|K|^2 = 0.197$  for radar backscatter from ice crystals and 0.93 for backscatter from rain. Because ALCOR transmits a frequency-modulated "chirp" pulse, the pulse length used in the above computation is not the transmitted pulse length but rather a compressed pulse length corresponding to the output of a pulse-compression network in the radar receiver. Comparisons of chirp and constant-frequency radar weather data from the TTR-4 radar at Kwajalein<sup>6</sup> showed that the computational factor determined from Eq. (6) above had to be increased by 3 dB for the chirp data. Thus  $10 \log C = 86.5$  for the ALCOR observations above the freezing level and 79.8 in rain. We used only the values from the left circular polarization (opposite to the transmitted polarization) for this analysis, as these are 15 to 20 dB greater than those received on right circular polarization for weather echoes.

The quantity  $Z$  is the factor of the received signal power which is dependent only on meteorological parameters. It is equal to the sixth moment of the particle size spectrum, and thus is not a direct measure of the water content which is proportional to the third moment, that is, the volume. The relation of reflectivity to water content depends on the spectrum of ice crystals or water drops in a cloud. For preliminary estimates of water content, used for pre-mission forecasting and for the quick look post-mission briefing, we used a Z-M equation appropriate to ice crystals:<sup>7</sup>

$$M = 0.038 Z^{0.529}, \quad (7)$$

above the freezing level. Below the freezing level we used a Z-M equation appropriate to tropical rain:

$$M = 0.011 Z^{0.43}, \quad (8)$$

6. Metcalf, J. I., Barnes, A. A., Jr., and Nelson, L. D. (1975) Water content and reflectivity measurement by "Chirp" radar, 16th Radar Meteor. Conf., Amer. Meteor. Soc., pp 492-495.

7. Heymsfield, A. J. (1973) The Cirrus Uncinus Generating Cell and the Evolution of Cirriform Clouds, PhD. Thesis, The University of Chicago.

derived from equations presented by Battan.<sup>8</sup> (It should be noted that this Z-M equation was derived from surface observations and is therefore not strictly applicable to observations in clouds; however, it is useful for preliminary estimates of the cloud water content.)

An SPA-40 RHI scope installed at the PRESS Control Center provided some weather reconnaissance data for the mission. Photographs of the RHI display, such as those in Figure 8, were used to obtain cloud layer heights and cell locations in the vicinity of the reentry corridor. This information was used both for forecasting the weather prior to launch and for locating cloud layers to be sampled during the radar-aircraft correlation operations. RHI scans made early on the mission day showed a thin layer at 2 km altitude and a thicker one between 10 and 12 km. Both layers extended some 60 km toward the east-southeast. An RHI scan about an hour after the RV impact showed no cloud layers, but several cells with tops at 6 to 8 km.

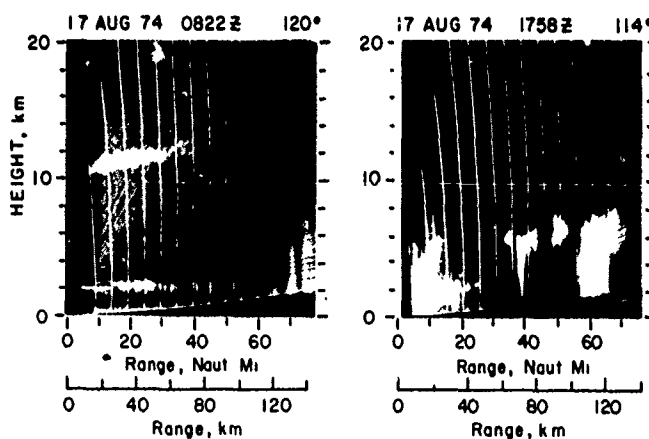


Figure 8. ALCOR RHI Scans During OT-45 Operations. Range markers are at intervals of 5 n. mi. (9.3 km). Cloud layer detected at 10 to 12 km altitude at 0822Z is not seen at the time of reentry. Extensive shower activity reaches to near 8 km altitude at 1758Z

Following vehicle impact a sequence of scans was made, once down each trajectory from 23 km to 0.5 km and once vertically over the radar, and repeated as shown in Table 2.\* The sequential scans on each trajectory provided a time history of the weather on the trajectory. The vertical scans were intended to reveal thin

\*RV numbers given in the letter report (12 September 1974) were erroneous: 1, 2, and 3 described there should be 2, 3, and 1, respectively.

8. Battan, L.J. (1973) Radar Observation of the Atmosphere, The University of Chicago Press.

layers which might be too weak to appear in the trajectory scans, since the minimum detectable signal level increases as the square of the slant range.

Reflectivity profiles derived from the B-6 data suggested the presence of weak echoes above 9 km on all the trajectories. However, the Lincoln Laboratory RTI films showed no weather echoes at these altitudes, so it is likely that the supposed echoes were due to noise level fluctuations. Weather was encountered below 6 km on the RV2 trajectory. The two scans of this trajectory, shown in Figure 9, indicate that this RV passed through a cell extending from 2.5 to 6 km. The change in

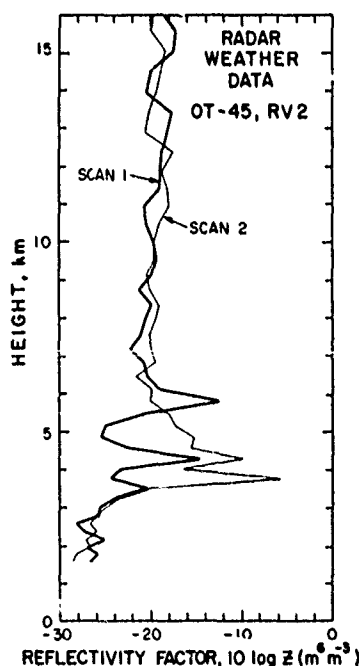


Figure 9. Profiles of Radar Reflectivity Factor  $Z$  on OT-45 RV2 Trajectory. These are derived from the PRESS B-6 data and presented in logarithmic form, with  $Z$  in  $\text{mm}^6 \text{m}^{-3}$ . Reflectivity values above 6 km and below 3 km correspond to the radar system noise level, or the minimum detectable reflectivity. Rapid changes in the weather structure are due to advection of cloud features through the reentry corridor during the 4-min interval

appearance of the reflectivity profile from one scan to the next was due to the small-scale variability of the cell combined with its motion during the 4.5-min interval between the scans. A range-height display of the first RV2 trajectory scan, derived from the full ALCOR data, is shown in Figure 10. This shows the details of the echoes in the vicinity of the trajectory. An echo was detected between 3 and 6 km with a maximum reflectivity of 7 dBZ at 4 km, but this maximum was not on the trajectory itself. Maximum reflectivity values on the trajectory were -11.4 dBZ ( $Z = 0.072 \text{ mm}^6 \text{m}^{-3}$ ) on scan 1 at 5.8 km and -5.6 dBZ ( $Z = 0.275 \text{ mm}^6 \text{m}^{-3}$ ) on scan 2 at 3.8 km. These signal values correspond to water content of 0.004 and 0.006  $\text{gm m}^{-3}$ , respectively, by Eq. (8).

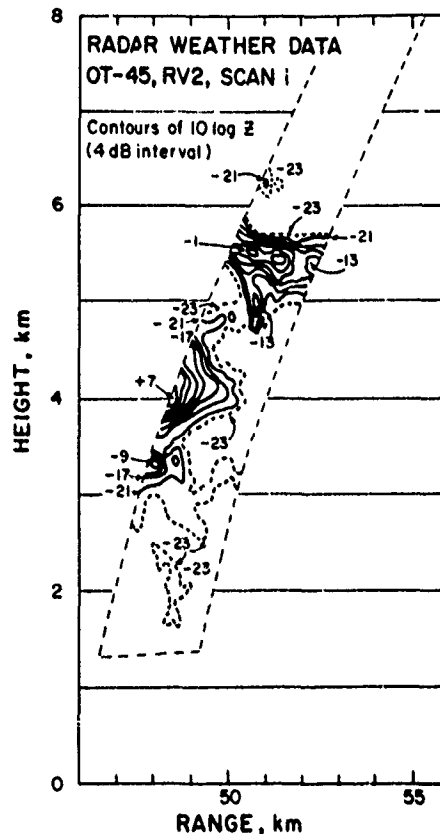


Figure 10. ALCOR Scan of OT-45 RV2 Trajectory at 1653Z, 17 August 1974. Contours are of  $10 \log Z$ , with  $Z$  in  $\text{mm}^6 \text{m}^{-3}$ . This display is derived from the original ALCOR data recorded across a 2.5-km interval in slant range. Nominal trajectory location is approximately 1/3 of the way across the array from the near-range side. Maxima at 5 and 5.5 km are beyond the trajectory at this time; maximum at 4 km is just moving into the field of view.

The vertical scan (Figure 11) revealed the thick clouds over Roi-Namur extending to about 11 km. A thin layer was detected at 13.5 km, but no clouds were observed at that height from the aircraft. It is unlikely that a cirrus layer producing this echo would have extended very far from the convective cells over Roi-Namur. The generally dry air at that level would have caused rapid evaporation of any cirrus blown out from the cell tops.

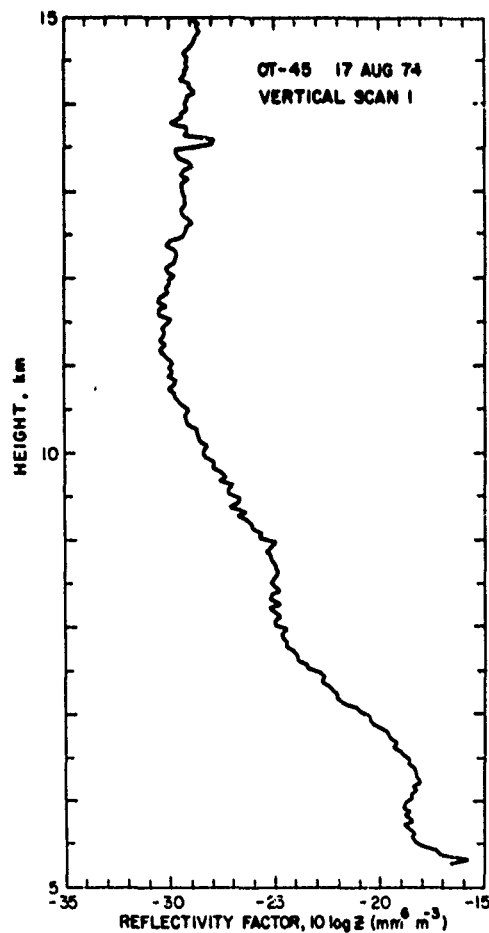


Figure 11. Profile of Radar Reflectivity Factor Z on ALCOR Vertical Scan at 1656Z, 17 August 1974. Echo from thick clouds over Roi-Namur extends to about 11 km. Thin layer at 13.5 km is probably cirrus associated with the deep convective activity

##### 5. PVM-8 WEATHER DESCRIPTION

During the period of the PVM-8 mission Kwajalein was located beneath an upper level ridge. During the day mid- and upper-level winds backed from south-easterly to easterly. Stable conditions under the ridge prevented significant convection from developing to the east of Kwajalein. The clear weather in that region insured minimum weather conditions at launch time.

A satellite pass at 0929Z, 5 October 1974 (Figure 12) showed Kwajalein in a generally clear area with unsettled weather 500 km east and west, and 200 to 300 km to the south-southeast.

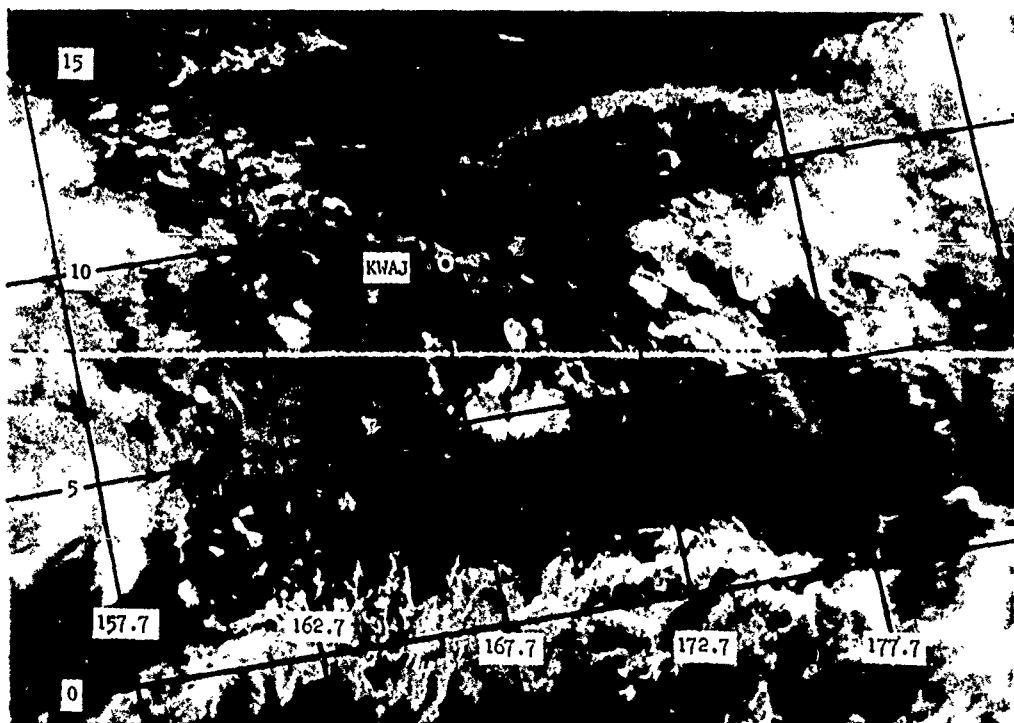


Figure 12. DMSP Satellite Infrared Data for 5 October 1974, 0929Z. Immediate vicinity of Kwajalein is mostly clear. Significant convective activity is located 200 to 300 km to the south-southeast and 500 km to the east and west

Rawinsondes were released from Kwajalein and Roi-Namur at 0645Z (Figure 13). The freezing level was 4.6 km and the tropopause at 16.4 km. Saturation occurred in the layer from 5.5 to 6.1 km on both soundings, close to the height of one of the layers observed by ALCOR. Humidity was above 90 percent between 5.0 and 6.5 km and about 60 percent in the 9 to 11 km region where ALCOR detected another layer. Winds at 4 to 5 km were from the southeast with a speed of  $8 \text{ m sec}^{-1}$ . At 12 to 14 km winds were from the northeast or north-northeast at about 7 to  $9 \text{ m sec}^{-1}$ . Winds elsewhere were generally from the east. Maximum speeds were 12 to  $14 \text{ m sec}^{-1}$  at 6.7 km and 12 to  $15 \text{ m sec}^{-1}$  at 14.6 km.

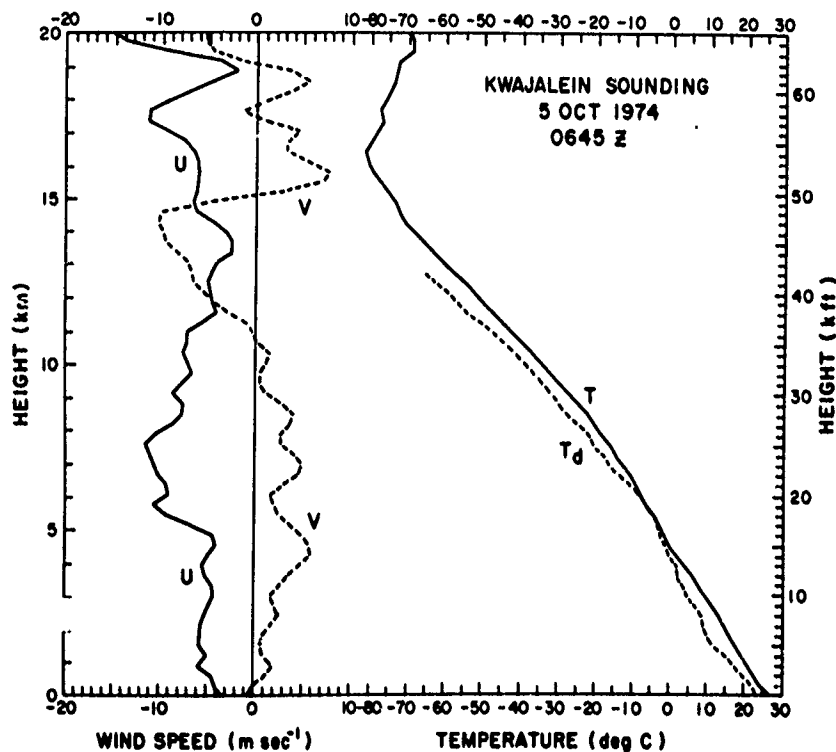


Figure 13a. Sounding From Kwajalein at 0645Z, 5 October 1974. Wind components are plotted toward the east (U) and toward the north (V). Layers of highest humidity at 5.0 to 6.5 km and 9 to 11 km coincide with heights of clouds detected by ALCOR. Winds were mostly from the east, except southeasterly at 4 to 5 and northeasterly at 12 to 14 km

The NWS 10-cm WSR-57 radar showed no echoes in the reentry area at the time of reentry. Figure 14 shows the PPI display at 0630Z. Most of the convective cells were south of Kwajalein Island, although one small cell was detected about 80 km to the north. This was dissipating and moving toward the west at the time of reentry.

During their pre-mission flights, the Citation and the C-130E aircraft reported that they encountered two distinct cloud layers. The lower one consisted of several thin layers of water clouds between about 3 and 6 km. The upper layer, between 9 and 12 km, was a non-homogeneous cirrus, consisting of some active generating cells and residual ice crystals of dissipating cells. As launch time approached, both layers became thinner and had numerous breaks in them.

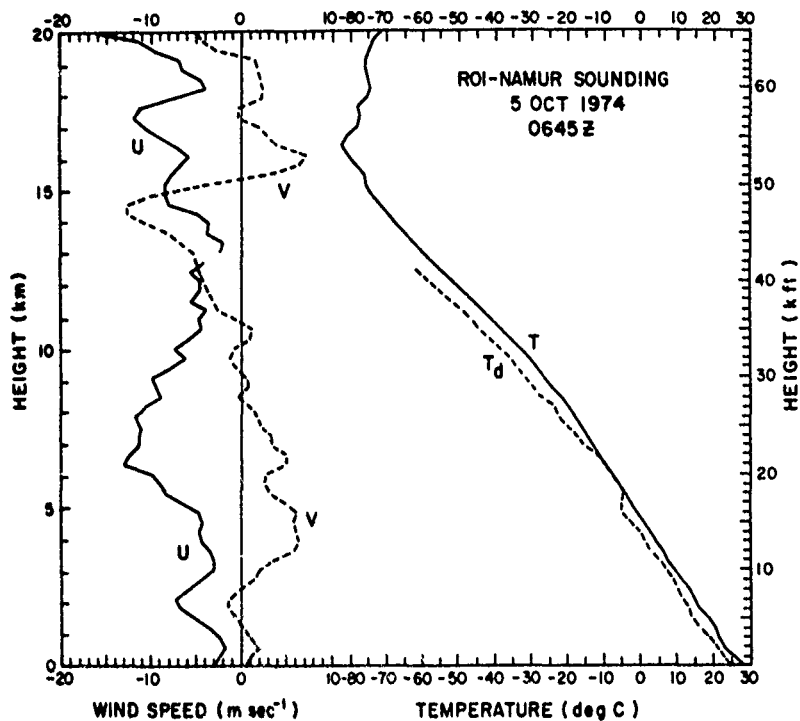


Figure 13b. Sounding From Roi-Namur at 0645Z, 5 October 1974.  
(See legend of Figure 13a)

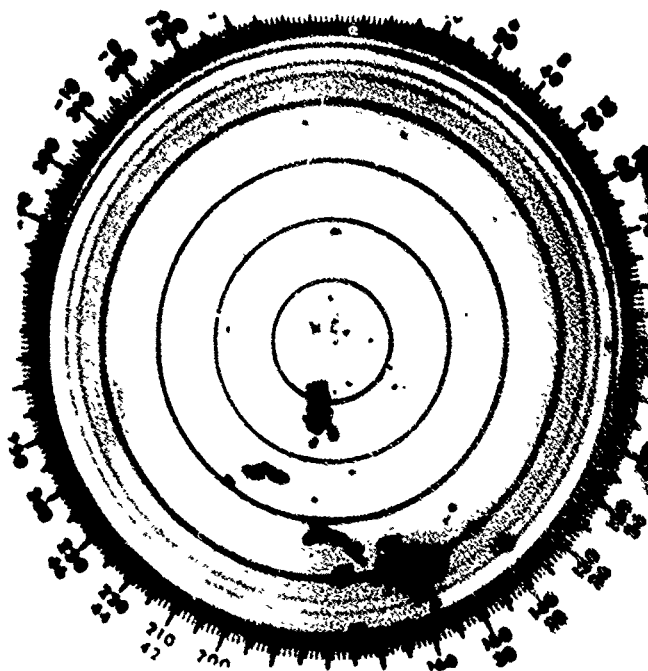


Figure 14. WSR-57 Radar PPI at 0630Z, 5 October 1974. Elevation angle is  $0^\circ$  and range markers are at 25 n. mi. (46.3 km) intervals out to 125 n. mi. (231.5 km). Precipitation cells are mostly 35 km or more to the south of Kwajalein. A small cell about 80 km north of Kwajalein is dissipating and moving toward the west

## 6. AIRCRAFT WEATHER OBSERVATIONS FOR PVM-8

Weather reconnaissance operations and quantitative cloud sampling operations were conducted by the AFSWC C-130E and the Citation. The cloud physics instrumentation on the C-130E is described in Appendix B and illustrated in Figure 15. The instrumentation on the Citation is described in Section 3 above, and in the MRI final report.<sup>3</sup> The C-130E operated below 9 km altitude, and the Citation up to about 12 km. Their operations on PVM-8 mission day are summarized in Tables 3 and 4. The SAI holographic camera was operated on this day, but only a few small particles were recorded.

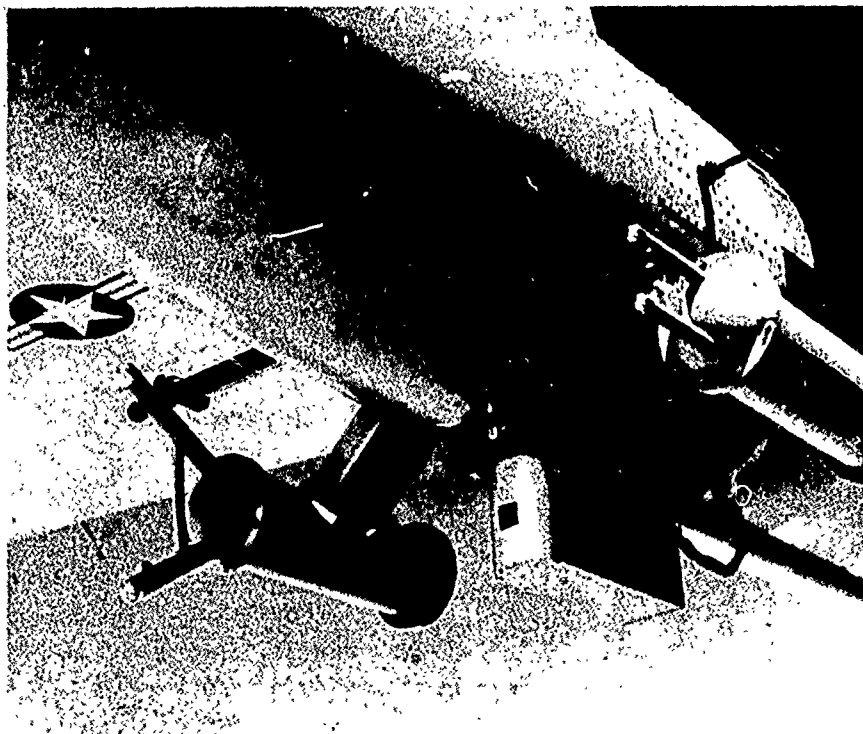


Figure 15. Instrumentation Pod Under Wing of C-130E (No. 40571). Instruments on pod (counterclockwise from upper left) are axially scattering spectrometer, precipitation particle spectrometer, foil sampler, cloud particle spectrometer, and Rosemont temperature sensor

Table 3. C-130E Operations at Kwajalein, 5 October 1974

Time GMT	Pressure Altitude		Remarks
	(kft)	(km)	
0200 to 0452	0 -28	0 -8.5	Takeoff and ascent in reentry corridor; Observations in corridor at 8.5 km
0733 to 0737	26 -17.5	7.9-5.3	Descent along target path
0804 to 0806	17.5	5.7*	} Correlation sampling with MPS-36 and ALCOR
0815 to 0818	20.5	6.7*	
0827 to 0830	25.5	8.3*	

\*Altitude from ALCOR tracking data

Table 4. Citation Operations at Kwajalein, 5 October 1974

Time GMT	Pressure Altitude		Remarks
	(kft)	(km)	
0455 to 0513	20-30	6.1- 9.1	Ascent along target path
0526 to 0529	30	9.1	
0533 to 0537	28	8.5	
0542 to 0545	26	7.9	
0556 to 0612	26-35	7.9-10.7	Ascent along target path
0615 to 0623	35-20	10.7-6.1	Descent along target path
0740 to 0748	32-17	9.8- 5.2	Descent along target path
0809 to 0812	17	5.4*	} Correlation sampling with MPS-36 and ALCOR
0822 to 0826	20	6.4*	
0834 to 0837	25	8.1*	
0843 to 0846	30	9.7*	
0851 to 0854	32	10.3*	

\*Altitude from ALCOR tracking data

The cloud particle probe normally installed in the C-130E was replaced by a PMS precipitation probe which had been in the WB-57F used earlier in the Minute-man Natural Hazards Program. The purpose of this substitution was to obtain comparisons of spectral distributions and total water content as determined from the two probes. Studies of these data are underway at AFCRL and at MRI.

The first flight of the C-130E was primarily for purposes of weather reconnaissance. After initial climb, the aircraft proceeded to the reentry corridor where

some cloud measurements were taken near the base of the upper cirrus layer. The Flight Director described the cirrus as "wispy and tenuous with numerous breaks," and the crystal habit was predominantly small columns and plates.

The Citation flew weather reconnaissance and cloud sampling operations in the reentry corridor between 0455 and 0623Z, sampling both of the cloud layers. The lower layer consisted of water droplets, with liquid water content about  $0.005 \text{ gm m}^{-3}$  during the early part of the flight. After reentry this was observed to have increased to about  $0.02 \text{ gm m}^{-3}$ . The Citation observed bullet rosette crystals in the upper cloud layer, with ice water content initially about  $0.005 \text{ gm m}^{-3}$ . The ice water content increased locally to about  $0.03 \text{ gm m}^{-3}$  near the time of reentry although the layer was patchy.

Following the reentry both aircraft made descents along the reentry corridor, and performed cloud sampling for correlation with ALCOR weather data. The Citation observed maximum water content of about  $0.03 \text{ gm m}^{-3}$  at 10.7 km altitude during the descent. The correlation flights followed tracks located about 7 km to either side of the RV1 trajectory (Figure 1), extending to about 30 km uprange from the target point. The aircraft flew these tracks in a "racetrack" pattern, moving in a counterclockwise direction. The data from the lowest two passes by each aircraft were analyzed with the assumption of 100 percent water drops. The third passes, near the base of the upper cloud layer, were in cirrus cloud deduced to be predominantly dendrites. The highest two passes by the Citation were through bullet rosette crystals. The quantitative data from these passes provided some good correlations between the aircraft and radar weather measurements, which are presented in the following section. The C-130E Flight Director reported being in the clear at all times during the descent and correlations, but because it was dark this visual report is not wholly reliable. In fact, some clouds were encountered by the C-130E during the correlation flights, with peak values of water content about  $0.004 \text{ gm m}^{-3}$  on Pass 1,  $0.01 \text{ gm m}^{-3}$  on Pass 2, and  $0.002 \text{ gm m}^{-3}$  on Pass 3. At this time the stars could be seen but were veiled in the thin cirrus above 8 km.

## 7. ALCOR WEATHER OBSERVATIONS FOR PVM-8

Weather data recorded by ALCOR in support of the PVM-8 mission are summarized in Table 5. Trajectory scans and one RHI scan were used for forecasting prior to launch. Following the reentry a scan was made once down each trajectory and once vertically over the radar. Another RHI scan was made later to aid in directing the aircraft correlation sampling.

Table 5. ALCOR/PRESS Weather Support for PVM-8, 5 October 1974

RHI scan at 0315Z			
Trajectory scans		Weather structure	Max WSI*
0115 to 0117		2.1- 4.2; 8.5-12.7 km	1.4 (RV1)
0310 to 0312		7.5-12.2 km	1.8 (RV2)
0512 to 0514		4.7- 5.3; 8.5-11.5 km	0.2 (RV2)
Post-impact scans		Weather Structure	
0641:25 to 0642:27	RV1	3.0- 5.7; 9.1- 9.9 km	
0642:46 to 0643:48	RV2	2.5- 5.1; 8.6-11.1 km	
0644:13 to 0644:26	Vertical		
RHI scan at 0750Z			
Aircraft Correlations	Alt (km)	Hdg (deg)	Aircraft
0803:21 to 0806:28	5.7	238	C-130E
0808:41 to 0812:33	5.4	238	Citation
0814:46 to 0817:55	6.7	058	C-130E
0820:50 to 0825:33	6.4	058	Citation
0826:40 to 0829:41	8.3	238	C-130E
0833:32 to 0836:57	8.1	238	Citation
0842:21 to 0846:12	9.7		Citation
0850:20 to 0853:47	10.3	200	Citation

\*WSI computed from Eqs. (3) and (7).

The pre-mission RHI scan (Figure 16) showed the low-level cloud layers reported by the C-130E below 5 km. The thick clouds observed between 5 and 9 km altitude were remnants of local convective activity. These clouds must have been moving rapidly away from the reentry corridor with the easterly wind at these heights, as neither of the aircraft reported clouds at these altitudes. The patchy structure of the highest layer at 10 to 12 km corresponds to the description by the aircrews. Another scan about an hour after reentry showed the principal layers sampled by the aircraft during the correlation operations. The variability of the weather is illustrated by the fact that no clouds were observed by ALCOR between 6 and 8 km altitude on the trajectories despite the presence of clouds at these altitudes before and after the reentry.

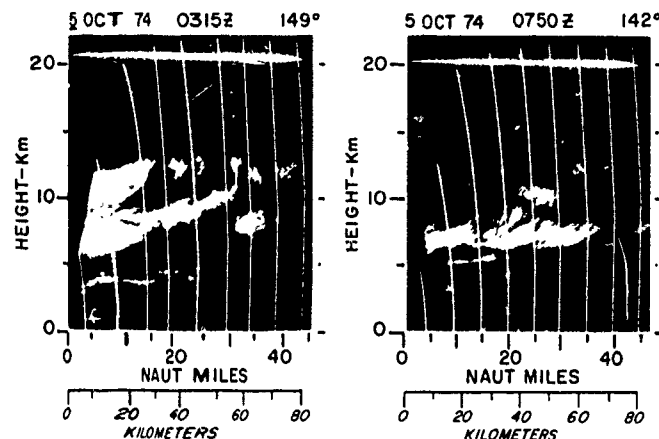


Figure 16. ALCOR RHI Scans During PVM-8 Operations. Range markers are at intervals of 5 n. mi. (9.3 km). Clouds reported by the aircraft during their first flights are seen below 5 km and between 10 and 12 km at 0315Z. Intermediate layer is probably related to convective cells northwest of Roi-Namur. Later RHI shows cloud layers at 5 km, 6 to 8 km, and 10 to 11 km at the time of the correlation sampling. Spatial variability of clouds is emphasized by absence of cloud at 6 to 8 km on the trajectories

Reflectivity profiles derived from the PRESS B-6 data are shown in Figure 17. RV1 passed through cloud layers at 14 km, 11 to 8 km, and 6 to 2.8 km. Maximum reflectivity values were -15.1 dBZ at 9.9 km ( $0.003 \text{ gm m}^{-3}$ ), and -1.2 dBZ ( $0.01 \text{ gm m}^{-3}$ ) at 3.6 km. RV2 passed through layers at about 13.5 km, 11.5 to 8 km, and 5.8 to 2.3 km. Maximum reflectivity values were -11.3 dBZ ( $0.005 \text{ gm m}^{-3}$ ) at 10.7 and 10.4 dBZ ( $0.033 \text{ gm m}^{-3}$ ) at 3 km. The highest layer encountered by each RV was just above noise, at -22 dBZ ( $0.0015 \text{ gm m}^{-3}$ ).

The reflectivity data for the trajectories are shown in Figures 18 and 19 in a range-height format. These both show the layer near 14 km noted in the reflectivity profiles (Figure 17), and the clouds between 8.5 and 11.5 km which had a marked cellular structure. The clouds below 6 km were even more convective in structure. The trajectories, however, did not generally intersect the largest reflectivity maxima in these cells. The vertical scan (Figure 20) showed a weak echo below 5.6 km with peak reflectivity of -10.5 dBZ, and an echo between 9 and 11 km with multiple maxima at 9.3 km (-3.1 dBZ) and 10.5 km (-10.1 dBZ). Thin layers were observed at 11.5, 13, and 13.5 km with reflectivity of -20 dBZ or less.

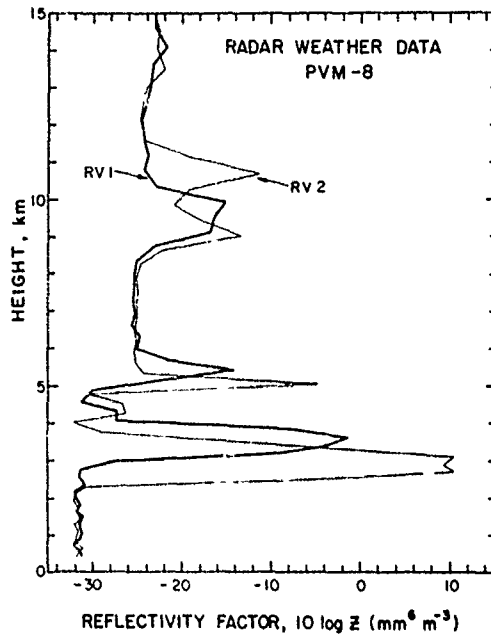


Figure 17. Profiles of Radar Reflectivity Factor  $Z$  on PVM-8 Trajectories. These are derived from the PRESS B-8 data and presented in logarithmic form, with  $Z$  in  $\text{mm}^6 \text{m}^{-3}$ . A thin layer is just discernable at 14 km. Primary layers are at 9 to 11 km and 2 to 6 km, with maximum water content at 10.8, 5.0, and 3.0 km (on RV2 trajectory)

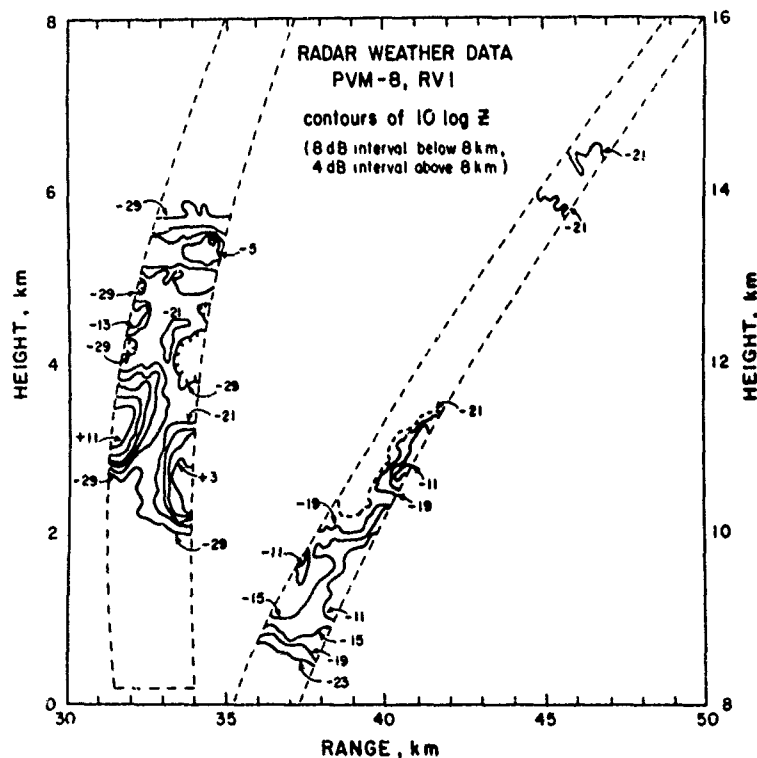


Figure 18. ALCOR Scan of PVM-8 RV1 Trajectory at 0642Z, 5 October 1974. Contours are of  $10 \log Z$ , with  $Z$  in  $\text{mm}^6 \text{m}^{-3}$ . Scan is split at 8 km, so that scale on left and right sides of figure refer to left and right portions of the scan, respectively. Clouds at all heights exhibit considerable spatial variability due to convection

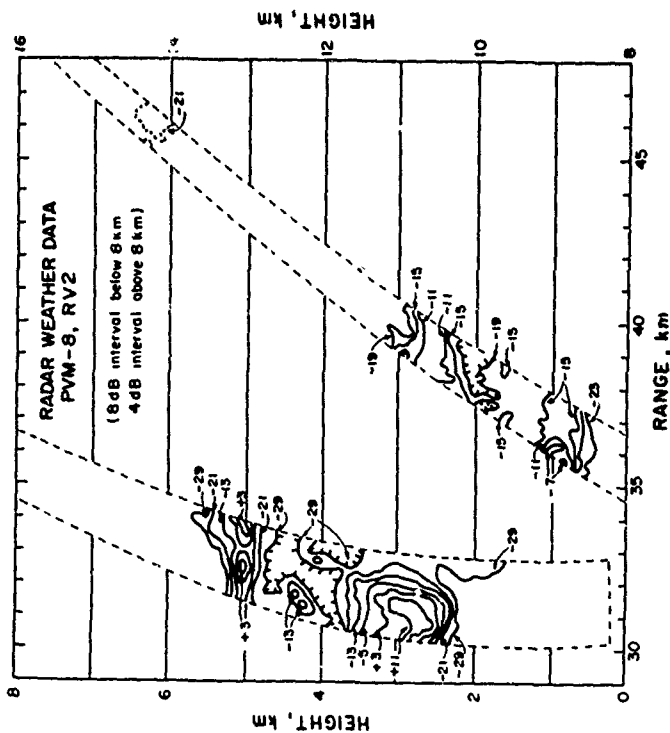


Figure 19. ALCOR Scan of PVM-8 RV2 Trajectory at 0643Z, 5 October 1974. Format is identical to that of Figure 18. Cloud heights are essentially the same as those in Figure 18, but individual features cannot be matched because of the distance between the trajectories

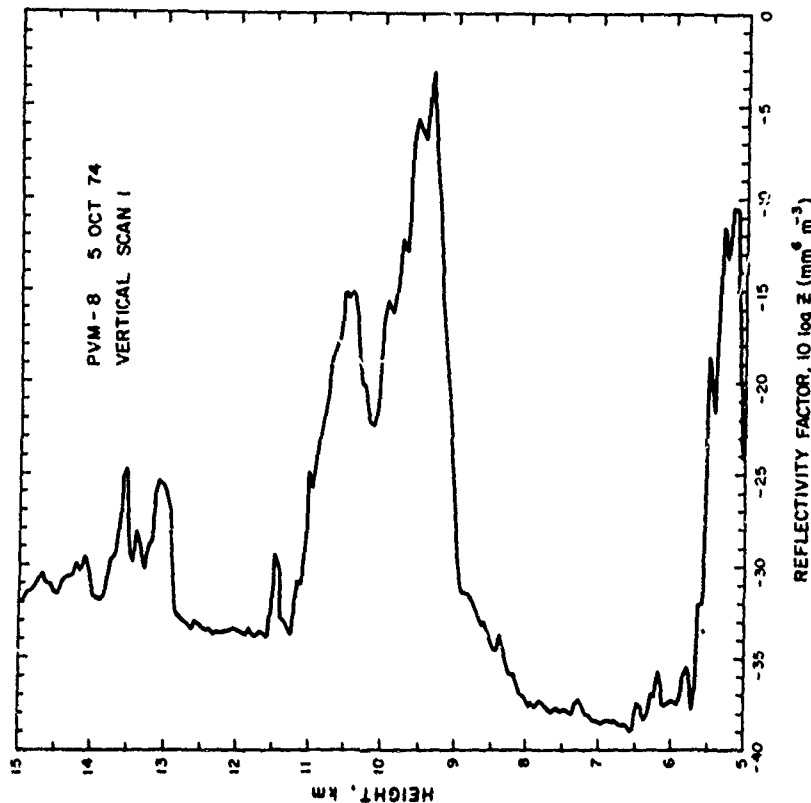


Figure 20. Profile of Reflectivity Factor Z on ALCOR Vertical Scan at 0644Z, 5 October 1974. Echo below 5.6 km has maximum corresponding to approximately  $0.005 \text{ gm m}^{-3}$  ice water content. Principal cloud layer between 9 and 11 km has about  $0.013 \text{ gm m}^{-3}$  maximum ice water content at 9.3 km. Thin upper layers have ice water content of  $0.0009 \text{ gm m}^{-3}$  or less, comparable to that of the 14-km layer on the trajectories

Radar weather data were recorded in conjunction with the instrumented aircraft using the link-offset mode described in Section 4. The C-130E made three passes between 5.7 and 8.3 km, and the Citation made five passes between 5.4 and 10.3 km. The numbers of counts and ranges of the computed M and Z values on the lowest pass by each aircraft were too small to define reliable correlation equations. Correlations derived from the C-130E for the 6.7 and 8.3 km passes are shown in Figure 21. The steep correlation line for Pass 2 (water droplets) was uncertain due to the small numbers of counts and the large scatter of the individual Z and M values about the line. The correlation of the radar and aircraft data for Pass 3 (in dendrite crystals) was excellent, with very small scatter of the points around the correlation line. However, the 10 to 15 dB difference in reflectivity values obtained from the aircraft and from the radar indicates that the computed values of water content may be 5 to 7 dB too low. Hence we used Eq. (8), rather than the equations we derived, for interpreting the lower part of the trajectory profiles. Correlations derived from the upper three passes by the Citation are shown in Figure 22. As with the

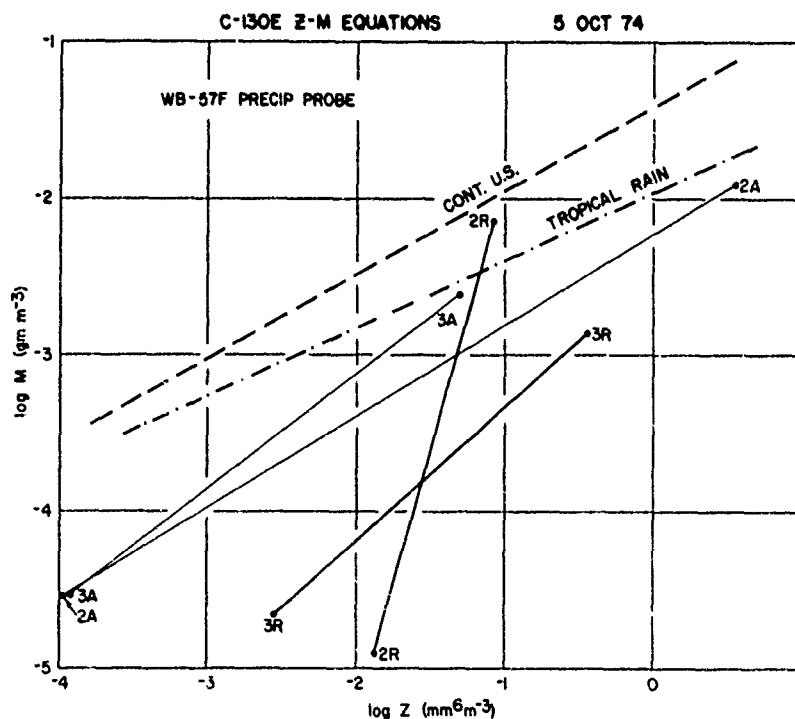


Figure 21. Z-M Equations Derived From C-130E PMS Data, 5 October 1974. Correlation lines derived exclusively from PMS data are designated "2A" and "3A"; those derived from PMS water content and ALCOR reflectivity data are designated "2R" and "3R". Eqs. (7) and (8) are shown for comparison

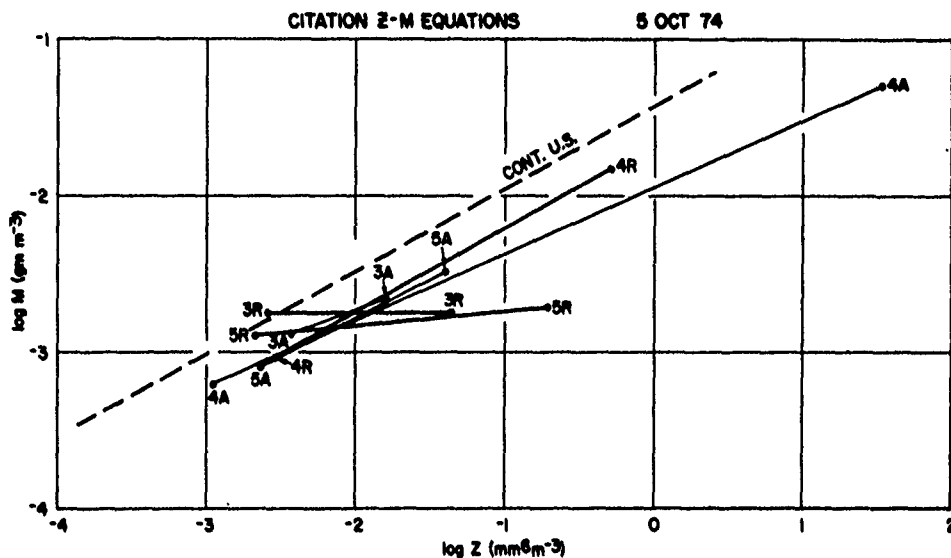


Figure 22. Z-M Equations Derived From Citation PMS Data, 5 October 1974. Correlation lines derived exclusively from PMS data are designated "3A" through "5A" for Passes 3 through 5; those derived from Citation PMS water content and ALCOR reflectivity data are designated "3R" through "5R". Line "4R" was used to interpret the uppermost layers on the trajectories. These lines are plotted only within the range of Z and M values used in their derivation. Eq. (7) is shown for comparison

lowest passes, the range of computed values of M precluded obtaining reliable correlation equations for Passes 3 and 5. However, Pass 4 at 9.7 km altitude yielded sufficient data for a good correlation. This equation was applied to the upper layers observed on the trajectories. The results of this analysis are presented in Section 9.

## 8. RVTO WEATHER SUMMARY

The reentry weather for the RVTO mission was almost completely clear. Because of the absence of clouds, the weather documentation was less comprehensive than for other missions. The principal weather observations were made by the C-130E aircraft, the NWS WSR-57 radar at Kwajalein, and ALCOR.

The C-130E flew a weather reconnaissance mission between 0000 and 0403Z. The flight was mostly in the reentry corridor, north to northeast of Kwajalein within a range of 185 km. During the initial climb the Flight Director observed a line of cumulus about 35 km northeast of Kwajalein, oriented southeast-to-northwest, with bases at 610 m and highest tops about 3 km. Scattered cirrus were present above

the aircraft, with base height estimated at 10.1 km, and a heavier cirrus layer could be seen about 300 to 350 km northeast of Kwajalein. At 0135Z the Flight Director reported that the cirrus above was dissipating, and that the clouds to the northeast showed no significant movement. About launch time, between 0346 and 0354Z, the C-130E flew a descent along the reentry corridor from 8.8 to 3.7 km on a heading of 230°. The Flight Director again observed the thin cirrus at 10.1 to 10.4 km, but noted that he could see through it easily. His assessment of the weather at that time was 1/10 coverage of very thin cirrus with scattered cumulus below 2 km.

Soundings were made from Kwajalein and from Roi-Namur immediately following the reentry. The most remarkable feature of the soundings (Figure 23) was the very low humidity, even at the lowest levels. Peak values in the lowest few hundred meters were about 80 percent, and the relative humidity dropped to less than 50 percent at 3 km. Between 4.5 and 8 km there were two layers of increased humidity,

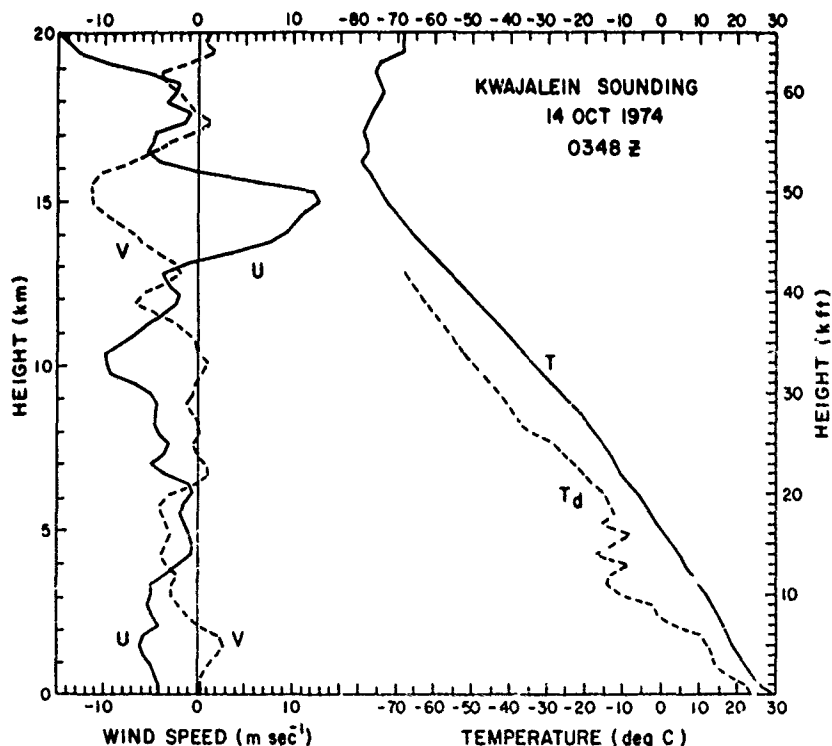


Figure 23a. Sounding From Kwajalein at 0348Z, 14 October 1974. Wind components are plotted toward the east (U) and toward the north (V). Low humidity throughout the depth of the sounding corresponds to the absence of clouds on this day. Winds are mostly from the east or northeast up to about 13 km, with a top speed of about  $9.8 \text{ m sec}^{-1}$  at 10.2 km. Between 13.5 and 15.8 km, just below the tropopause, the wind is northwesterly with a maximum speed of  $17 \text{ m sec}^{-1}$  at 14.9 km

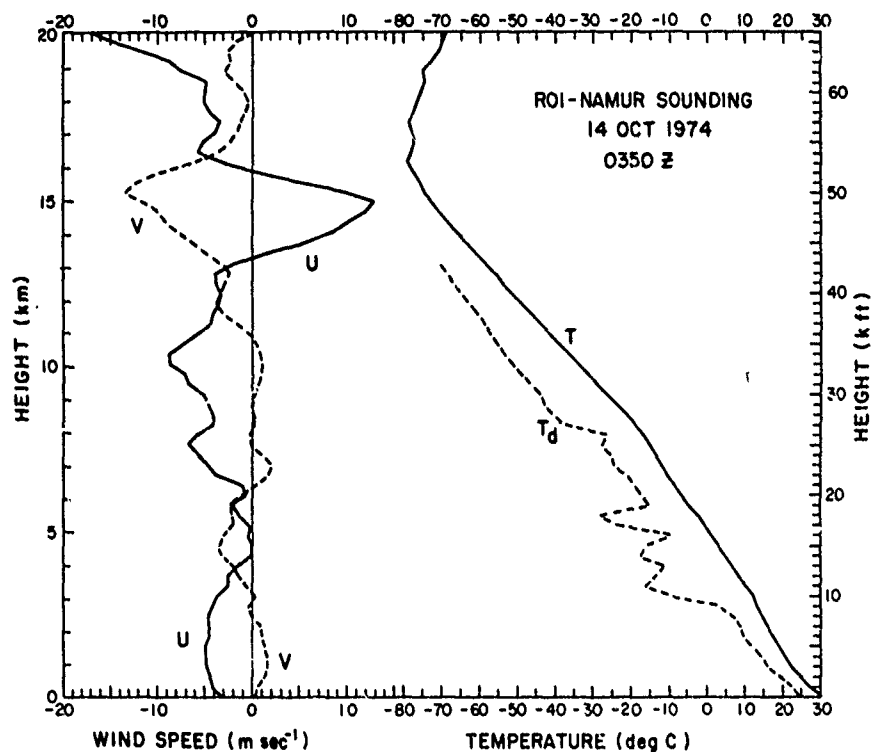


Figure 23b. Sounding From Roi-Namur at 0350Z, 14 October 1974  
(See legend of Figure 23a)

but the peak values were only about 50 percent; elsewhere the relative humidity was 25 percent or less. Winds were from the east or east-southeast up to about 3 km, with maximum speed of  $7 \text{ m sec}^{-1}$ . Between 3 and 6.4 km the wind backed to northerly, with maximum speed of  $4 \text{ m sec}^{-1}$ , and veered to easterly again. Winds were easterly or east-southeasterly up to 11 km with maximum speed of  $10 \text{ m sec}^{-1}$ . The wind backed to northerly at 13 km and northwesterly at 13.7 to 15.2 km with maximum speed of  $17 \text{ m sec}^{-1}$ , just below the tropopause which was at 16.1 km. Above the tropopause the wind was generally easterly to the top of the soundings, with speed increasing to about  $32 \text{ m sec}^{-1}$  at 24 km.

The WSR-57 PPI scan about the time of reentry (Figure 24) showed no precipitation cells in the reentry corridor, or in any of the area north of Kwajalein. A few weak echoes observed at 25 to 45 km range to the south and southeast may have been due to convective cells, but these were not significant, as the individual echoes did not persist for more than about 1/2 hr.

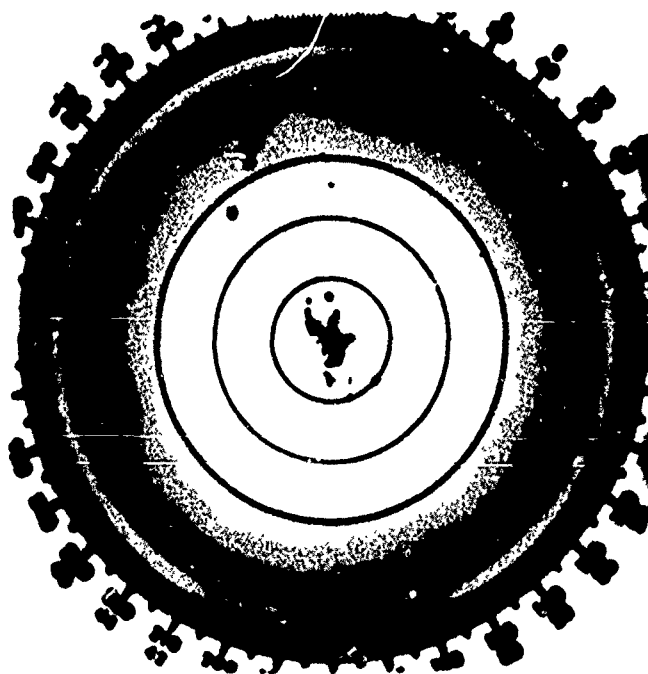


Figure 24. WSR-57 Radar PP 0405Z, 14 October 1974. Elevation angle is  $0^\circ$  and range markers are at 25 n. mi. (46.3 km) intervals out to 125 n. mi. (231.5 km). A few small cells are located just south and southeast of Kwajalein. A line of cells about 120 to 190 km to the north-northwest is dissipating as it moves toward the west. Echoes from the atoll islands can be seen to the north and northwest within about 40 km range

ALCOR weather scans were made along the reentry trajectory following RV impact, as listed in Table 6. No weather echoes were detected on the trajectory, implying that any clouds which might have been present were less than the minimum detectable signal level corresponding to about  $0.003 \text{ gm m}^{-3}$  ice water content. Vertical scans over the radar, with a lower minimum detectable signal level, showed only thin layers at 5.2, 8.3, and 13.5 km, with maximum reflectivities of -37.5, -33.0, and -27.7 dBZ, respectively (Figure 25). These may have been due to refractive index fluctuations associated with humidity gradients and wind shear, but were equivalent to ice water content of  $0.001 \text{ gm m}^{-3}$  or less, by Eq. (7), in all cases. The WSI computed for these values of ice water content is less than 0.01.

Table 6. ALCOR/PRESS Weather Support for RVTO, 14 October 1974

Time <sup>1,2,3</sup> (GMT)	Scan mode and remarks
2352 (13 October)	Trajectory scan, no clouds
0417:56 to 0418:59	No clouds on trajectory
0419:24 to 0419:37	Vertical scan
0420:00 to 0421:03	No clouds on trajectory
0421:27 to 0421:40	Vertical scan

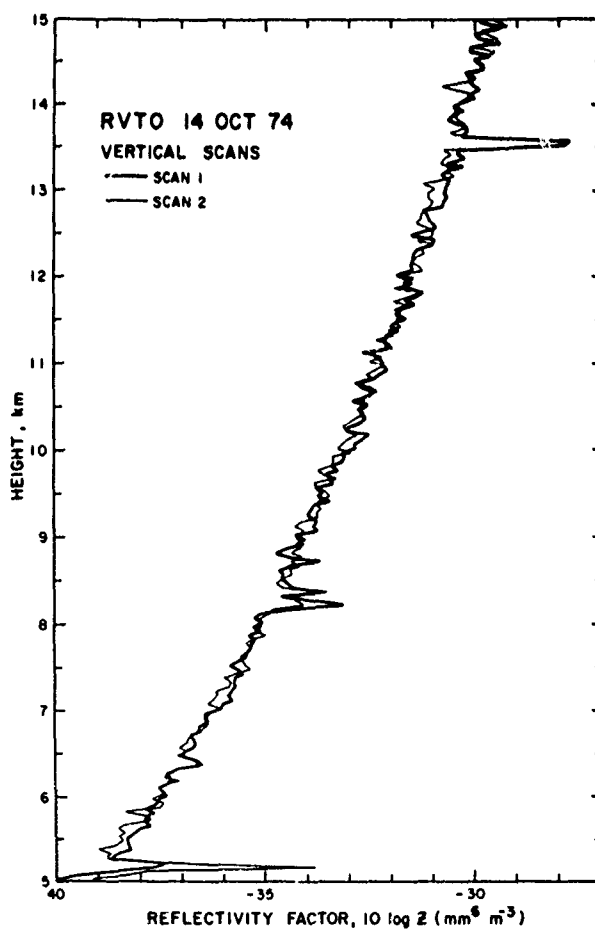


Figure 25. Profile of Reflectivity Factor Z on ALCOR Vertical Scans at 0419 and 0421Z, 14 October 1974, following RVTO Reentry. Thin layers at 5.7, 8.3, and 13.5 km correspond to ice water content of 0.001 gm m<sup>-3</sup> or less

## 9. CONCLUSIONS

### 9.1 OT-45 Summary

Water content profiles derived from ALCOR data for the OT-45 trajectories are shown in Figure 26. Only RV1 and RV2 encountered radar-detectable clouds, and only below 6 km. Above this altitude the ice water content values, obtained from the B-6 radar data by the Citation Z-M equations described in Section 3, represent the approximate minimum detectable values on the three trajectories. The thin layers observed below 4 km on the RV1 trajectory may have extended across the other trajectories without being detected, as the other trajectories were further from the radar. The layer observed at 13.5 km on the vertical scan may have extended to the reentry corridor, but this is highly unlikely due to the low humidity away from the cloudy area that was over the radar.

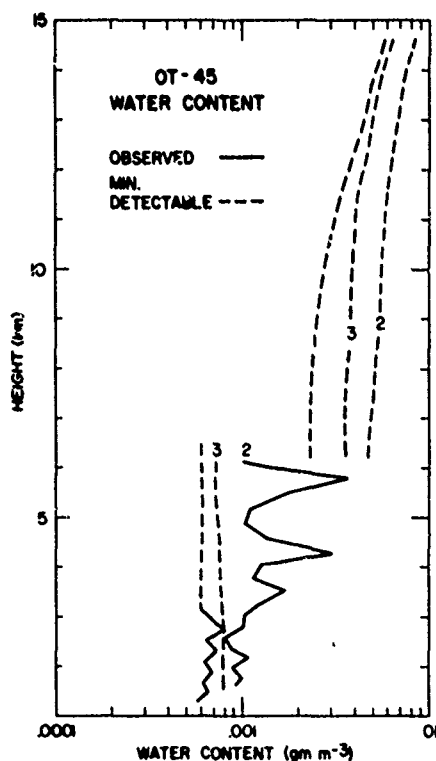


Figure 26. Profiles of Water Content on the OT-45 Trajectories. These are derived from the B-6 radar data by means of the Z-M equations shown in Figure 6. Broken line segments indicate approximate minimum detectable water content. Water content values above and below 6 km are computed for ice and liquid, respectively. Clouds are detected only below 6 km on the RV1 and RV2 trajectories

The portion of the trajectories below 6 km was interpreted by Eq. (8) in the absence of correlation measurements in rain on this day. Measurements on other days indicate that the values of liquid water content derived by this equation are

accurate to better than 5 dB, or a factor of 3. Based on the observed clouds, the WSI was about 0.03 for RV2 and less than 0.01 for RV1.

The weather in the Kwajalein area was mostly convective cells, generally located to the north of the reentry corridor. One cell moved through the corridor just before reentry, and was just northeast of the corridor at reentry time. The Citation sampled this cell and obtained maximum water content of  $0.3 \text{ gm m}^{-3}$ . Elsewhere the water content computed from the aircraft data was less than  $0.0072 \text{ gm m}^{-3}$ , and very small numbers of particles were counted.

## 9.2 PVM-8 Summary

Water content profiles encountered by the PVM-8 reentry vehicles are shown in Figure 27. The upper parts of the profiles were derived from the B-6 radar data by means of the Z-M correlation equation obtained from Citation Pass 4, at 9.7 km; these values of ice water content are accurate to about 3 dB, or a factor of 2. Because of the uncertainty of the water content values derived from the C-130E, Eq. (8) was used to derive the water content profiles below 6 km; as noted above, these values are accurate to within a factor of three.

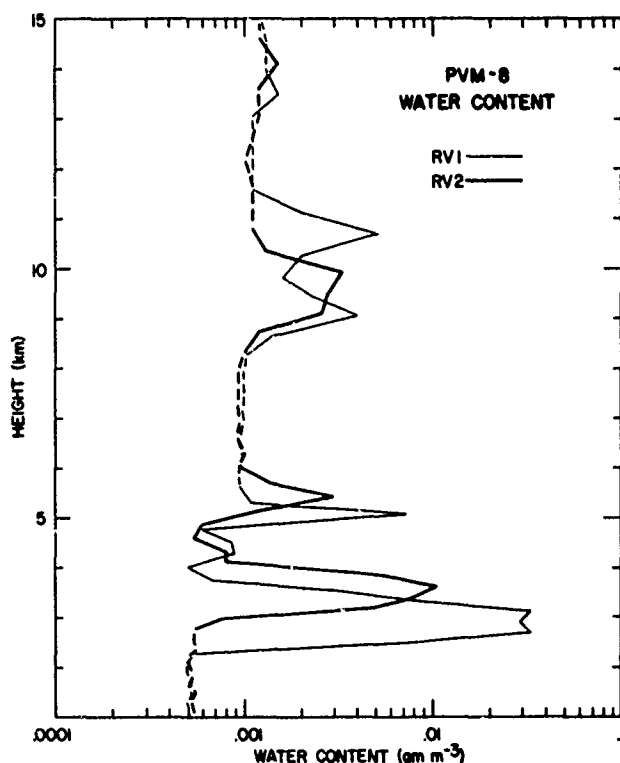


Figure 27. Profiles of Water Content on the PVM-8 Trajectories. These are derived from the radar reflectivity profiles (Figure 17) by means of the Z-M equations described in Section 7. Broken line segments between the layers indicate minimum detectable water content. Water content values above and below 6 km are computed for ice and liquid, respectively

Very little convective activity was present in the Kwajalein area. Two principal cloud layers were observed on the trajectories and reported by the C-130E and Citation aircraft. The lower one was composed of multiple layers of thin water clouds between 3 and 6 km. The upper one was a cirrus layer with a non-uniform cellular structure. A very thin cloud layer was observed near 14 km on the trajectory scans and the radar vertical scan. Maximum values of water content observed in the cloud layers by the Citation were  $0.02 \text{ gm m}^{-3}$  in the lower layer and  $0.03 \text{ gm m}^{-3}$  at 10.7 km near the time of reentry. The three layers observed on the trajectories gave increments of WSI from highest to lowest altitude as follows: 0.02, 0.05, and 0.04 for RV1; and 0.02, 0.08, and 0.09 for RV2.

### 9.3 Conclusions

Several factors affect the validity of the water content profiles presented above. Spatial variability of the weather structure makes it difficult to obtain exact measurements of the weather actually encountered by the reentry vehicles. Previous results<sup>9</sup> have shown that the WSI can change by almost a factor of 2 in five min. The procedure of making the sequential trajectory scans is adequate to identify any significant variations in the trajectory weather. (Other radar requirements prevented obtaining second scans of the PVM-8 trajectories.) Any improvement in documenting the weather by radar could only be achieved by a dedicated weather radar scanning the trajectories at the moment of reentry. A related problem is that the weather scans were made on nominal trajectories rather than on the actual trajectories, but the deviation of the Minuteman RV's from their nominal trajectories is generally not significant from the meteorological point of view.

Derivation of Z-M equations for interpreting the radar data is difficult in "minimum weather" situations. Thin clouds may have too small a spread of water content values to define a good correlation line, as was true for some of the PVM-8 measurements, or the reflectivity values measured by the radar may be too close to the system noise level, as was observed in conjunction with OT-45. Furthermore, thin cloud layers can develop or dissipate or advect into or out of the reentry corridor in the time between the reentry and the aircraft sampling. Nominal Z-M equations such as Eqs. (7) and (8) are adequate for defining an approximate minimum detectable level, and obtaining approximate values of water content in clouds. Improved numerical results obtained from aircraft-radar correlations close to the time of a particular mission differ from the preliminary estimates by much less than an order of magnitude in cases we have analyzed.

9. Metcalf, J.I., Barnes, A.A., Jr., and Kraus, M.J. (1975) Final Report of PVM-5 Weather Documentations, AFCRI-TR-75-0302.

The accuracy of the PMS data reduction is dependent on instrument performance and on selection of ice crystal habit. A recent study by Heymsfield<sup>10</sup> has shown that the use of different crystal habits can change the computed ice water content values by factors of 3 to 4. The selection of crystal habit is critical for obtaining results of highest accuracy. However, if the accuracy of ice water content values is not required to be better than about 5 dB (a factor of 3), a nominal Z-M equation can be used and the crystal habit is of less importance.

The experimental techniques used for the reentry weather documentation have proven to be highly effective in terms of pre-mission weather evaluation, rapid access to data for "quick-look" analysis, and correlation of aircraft and radar data. Accomplishment of the latter objective was limited in the present cases primarily by the lack of significant weather on the mission days. The techniques included the use of the SPA-40 RHI display at the PRESS Control Center, the computation of water content profiles in near-real-time from the data on the PRESS B-6 tape, and the link-offset mode of obtaining the Z-M correlation data.

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10. Heymsfield, A. J. (1975) Simultaneous aircraft and Doppler radar observations of a deep stratiform layer, Part 1: Aircraft measurements and microphysical calculations, 16th Radar Meteor. Conf., Amer. Meteor. Soc., pp 433-440.

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5. Jahnsen, L.J. (1975) Utilization of SAMSO Airborne Holocamera for Cloud Physics Measurements, MRI 75 FR-1331, Meteorology Research, Inc., Altadena, Calif.
6. Metcalf, J.I., Barnes, A.A., Jr., and Nelson, L.D. (1975) Water content and reflectivity measurement by "Chirp" radar, 16th Radar Meteor. Conf., Amer. Meteor. Soc., pp 492-495.
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8. Battan, L.J. (1973) Radar Observation of the Atmosphere, The University of Chicago Press.
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## Acronyms & Symbols

ABRES	Advanced Ballistic Reentry Systems
AFCRL	Air Force Cambridge Research Laboratories
AFSWC	Air Force Special Weapons Center
ALCOR	ARPA-Lincoln C-band Observables Radar
ALTAIR	ARPA Long-range Tracking and Instrumentation Radar
ARPA	Advanced Research Projects Agency
CDPC	Central Data Processing Computer
DMSP	Defense Meteorological Satellite Program
ERT	Environmental Research and Technology, Inc.
GMT	Greenwich Mean Time
KMR	Kwajalein Missile Range
KREMS	Kiernan Reentry Measurements Site
M	Water content (liquid or ice), $\text{gm m}^{-3}$
MRI	Meteorology Research, Inc.
NWS	National Weather Service
OT	Operational Test
PMS	Particle Measuring Systems, Inc.
PPI	Plan Position Indicator
PRESS	Pacific Range Electromagnetic Signature Studies
PVM	Production Verification Missile
RH	Relative Humidity
RHI	Range Height Indicator
ROCC	Range Operations Control Center

RTI	Range Time Intensity
RV	Reentry Vehicle
RVTO	Reentry Vehicle Test Observables
SAC	Strategic Air Command
SAI	Science Applications, Inc.
SAMSO	Space and Missile Systems Organization
SAMTEC	Space and Missile Test Center
TRADEX	Target Resolution and Discrimination Experiment
TTR	Target Tracking Radar
WSI	Weather Severity Index
Z	Radar reflectivity factor, $\text{mm}^6 \text{m}^{-3}$
Z	Greenwich Mean Time

## Appendix A

### Derivation and Processing of Press B-6 Data

From each radar pulse the four signal values in gates 51, 52, 53, and 54 (centered about the radar tracking point) were examined to determine the maximum. Prior to the end of August 1974 this maximum value was stored in a memory unit which was updated for each successive pulse. After that time the maximum values from all pulses were retained and averaged for each 1/10 sec. Once every 1/10 sec an encoded value of radar cross-section was transmitted to the PRESS computer and recorded on the "B-6" tape. Prior to the end of August 1974 this was a single-pulse maximum value near the tracking point. Subsequently this was an average of the selected maximum values from about 20 successive pulses. In consultation with personnel at PRESS we developed a program to average these values over 1-sec intervals and compute the reflectivity factor  $Z$  by Eq. (5). Listings of the 1-sec averaged  $Z$  values provided the data for Figures 9 and 17 above. The program also computed  $M$  by Eq. (7) and  $WSI$  by Eq. (3) for purposes of pre-mission weather evaluation.

A future report in this series will describe the data processing in more detail. The "peak selection" scheme introduced a bias which partially offset the 3 dB error in the constant in Eq. (5) which was written into the PRESS program. The B-6 reflectivity data for OT-45 presented above were approximately 1.7 dB low; those for PVM-8 were approximately 0.8 dB low. This correction was not included in the reflectivity profiles shown above, and is not needed if the reflectivity data are interpreted by  $Z$ - $M$  equations obtained from correlation of aircraft and ALCOR data. However, if  $Z$ - $M$  equations derived exclusively from aircraft data or obtained from the scientific literature are used for the interpretation, then the correction

is needed. The radar data were corrected as necessary for the derivation of the water content profiles shown in Figures 26 and 27.

## Appendix B

### C-130E Instrumentation

Three one-dimensional particle spectrometers measure the sizes of hydrometeors encountered by the aircraft. These were built by Particle Measuring Systems, Inc., Boulder, Colorado. An axially scattering spectrometer measures particles in the range of 1 to 31  $\mu\text{m}$ , and two optical array spectrometers cover the ranges 30 to 310  $\mu\text{m}$  (cloud particle spectrometer) and 315 to 4287  $\mu\text{m}$  (precipitation spectrometer). Each probe records particle counts in fifteen channels representing approximately equal size increments within the range of sizes given above. By considering the probe geometry and aircraft speed these counts are converted into number concentrations which transform readily into a particle size distribution. An onboard display permits the operator to determine the size distributions while in flight. Data from this instrument are also recorded on a digital, computer-compatible magnetic tape for post-mission analysis.

The Foil Sampler, built by Meteorology Research, Inc., is a direct mechanical replicator consisting of a thin sheet of aluminum foil that is pulled, at constant speed, across a shuttered opening. Hydrometeors hit the foil and create imprints which are replicas of their size and shape. The foil replicator covers the range of sizes from 50  $\mu\text{m}$  to 5 mm. Particles smaller than 50  $\mu\text{m}$  will not make an imprint on the foil. Analysis of the foil is a laborious process requiring the eyes and mind of an experienced analyst.

The Formvar Replicator physically captures hydrometeors on a moving film which is coated with a fast-drying mixture of Formvar and chloroform. The drying rate is sufficiently fast that ice particles do not melt out of shape before the Formvar dries around them. Particles larger than 2  $\mu\text{m}$  can be sampled. Replication of

ice crystals is good up to about 500  $\mu\text{m}$ ; liquid droplets are replicated well only to about 50  $\mu\text{m}$  diam due to breakup of larger drops. Dry nitrogen is used to dry the coating and to provide positive pressurization of the instrument. This reduces fragmentation by reducing the particle speed at impact. The films are analyzed after each flight by means of a photo-analyzer (stop-motion) projector. This instrument was built by the Desert Research Institute of the University of Nevada.

The Liquid Water Content Indicator was built by Johnson-Williams Products, Mountain View, California. Water droplets strike one of two calibrated resistance wires of a balanced bridge. As the droplets absorb heat from the wire the bridge becomes unbalanced. The magnitude of the imbalance voltage is a measure of the LWC encountered. This instrument is designed to work in liquid clouds composed of droplets from 10 to 50  $\mu\text{m}$  diam, since larger droplets and solid particles have an unknown cooling efficiency. Therefore, this device is not useful in clouds containing rain, but it does detect supercooled droplets in ice clouds.

The Dewpoint/Frostpoint Temperature Sensor is a thermistor mounted on a thermoelectrically cooled mirror that is maintained at the highest temperature at which dew or frost will form. As the reflectivity of the mirror is reduced by the film of dew or frost, a monitoring photoelectric circuit senses the change and regulates the cooling unit. The output of this instrument is a voltage proportional to the dewpoint (or frostpoint) temperature. This instrument was built by the Environmental Equipment Division of EC&G, Inc., Waltham, Massachusetts.

The Rosemont Temperature Probe is a high precision, rapid-response instrument. Its output is a voltage which varies as a function of dynamic heating (true airspeed) and density (altitude) as well as the actual temperature. The Rosemont Temperature Probe is built by Rosemont, Inc., Minneapolis, Minnesota.

A Pressure Altimeter is used to determine the aircraft's operating altitude. Its output is a voltage proportional to the pressure altitude.

The Snow Stick is an aluminum rod that is used to determine ice crystal habit and size while flying through cirrus cloud or snow. At one end are four flat faces, painted black and marked with 1-cm squares. The rod is inserted through the side of the aircraft so that the sampling areas are 30 cm into the airstream. The operator can rotate the stick as necessary to bring each face perpendicular to the airstream. As snow crystals impinge on the stick the flight director can make judgments as to the crystal size and type.

The Time Code Generator provides a digital readout of Greenwich Mean Time (GMT) in hours, minutes, and seconds. This information is recorded on the data tape recorders and also displayed at each project-crew position within the aircraft.

The 16 mm Nose Camera is a time lapse camera controlled by the flight director. It is used to photograph cloud conditions for later analysis.

A Voice Tape Recorder is used by all participants in the mission. Most recorded information comes from the flight director, but any crewman may record unusual observations.

The PDP 8/I Computer processes digital data (PMS counts, Time) or analog data (airspeed, heading, J-W LWC, altitude, temperature) in real time aboard the aircraft. The PDP 8/I is built by the Digital Equipment Corp., Maynard, Mass.